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MASSACHUSETTS AGRICULTURAL COLLEGE

THIRTY-SEVENTH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

REPORT OF THE DIRECTOR FOR THE FISCAL YEAR ENDING NOV. 30, 1924, PUBLISHED IN ACCORDANCE WITH THE PROVISIONS OF SECTION 32 OF CHAPTER 30 OF THE GENERAL LAWS

Being Parts III and IV of the Sixty-Second Annual Report of the Massachusetts Agricultural College

A Record of the Forty-Second Year from the Founding of the State Agricultural Experiment Station

DEPARTMENT OF EDUCATION
THE COMMONWEALTH OF MASSACHUSETTS

Publication of this Document approved by the Commission on Administration and Finance

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MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION.

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REPORT OF THE DIRECTOR

SIDNEY B. HASKELL.

SIGNIFICANT DEVELOPMENTS OF THE YEAR.

The best portrayal of the work of the year ending December 1, last, is in terms of service to the agricultural industries of the State, rather than in terms of the work of the several departments of the Experiment Station. In the following paragraphs, therefore, we have attempted to state the more important events of the year, classified as just indicated.

Animal Husbandry and Dairying.

The most important agricultural industry of the State is dairying, whether the basis of judgment be total value of product, area of land used in production, or numbers of men and women engaged in the industry. Contributions to this great industry are being rendered by four different departments of the Experiment Station. The Department of Plant and Animal Chemistry carries on studies in animal nutrition and on the properties of feeding stuffs. The Departments of

Agronomy and of Botany are associated in certain studies with reference to crops produced for feed for dairy animals; and the Department of Agricultural Economics is making a thoroughgoing study of our dairy market.

In the studies in animal nutrition two projects of great promise are: first, a study of substitutes for milk in the rearing of dairy calves; and second, the role of mineral constituents in the ration of dairy animals. In both cases the project bears on an economically significant problem. The relatively high price at which most milk produced in Massachusetts is sold makes its use for animals economically impracticable; whereas the poverty in lime of many Massachusetts soils makes the study of the role of mineral supplements essential. A progress report on the former project has been prepared for publication, and will shortly be printed as a Station bulletin.

In the agronomic field the most significant work now under way is study of the improvement of permanent pastures. The fact that such improvement is possible has been abundantly demonstrated. The next step must be to carry this work into the field to determine facts as they apply to different soil types and pasture conditions in the several geographical subdivisions of the State. This work is exceedingly important; for our New England dairymen, operating usually on rather poor pastures, often overgrown with brush and weeds, are finding increasing difficulty in competing with dairymen located where pastures are still in better condition.

Finally, the study recently completed on the New England dairy market, supported cooperatively by the College and the Bureau of Agricultural Economics of the United States Department of Agriculture, is of outstanding significance. For the first time facts relating to the marketing problem of the Massachusetts and New England dairy industry are brought together within the compass of a single volume. This work when published should be of immense value to the farmers of the State, as a basis for developing their marketing program.

Fruit Production.

Five different departments of the Experiment Station have cooperated this past year in furthering projects having to do with the production and marketing of Massachusetts fruit. These are the Departments of Pomology, Entomology, Botany, Plant and Animal Chemistry, and Agricultural Economics.

At the home station, results secured in experimental orchards show strikingly the superiority of the sod mulch with nitrate method of treatment over against cultivation of the producing orchard. As far as is known to us, the facts in this comparison have been established for the first time. The significance to our Massachusetts orchard industry lies in the fact that most of our orchards are located on hilly land, on which the advantage of the sod mulch system of management over against cultivation is obvious. The other work of the department, having to do particularly with methods of tree and soil management, is of increasing value with every passing year.

The work in nursery certification carried on under the supervision of the Station, but without cost to the State or drain on Experiment Station funds, and under the general auspices of the Massachusetts Fruit Growers' Association, has progressed rapidly during the year. The following table shows the progress of the work since it was initiated in 1921:

Year	Number of Trees Certified	Number of Trees Refused	Total	Number of Nurseries Examined
1921	2,580	267	2,847	1
1922	8,437	438	8,875	2
1923	65,910	905	66,815	3
1924	125,609	3,505	129,114	6

The success of the work thus far has abundantly justified the expense of the original research project.

In disease control studies the Department of Botany has brought to a successful close its investigation of apple scab control in the eastern part of the State. As a result of the work of the Station, apple scab is being controlled to a very large degree. The season's work also contributed to our knowledge of the relative values of dusts versus sprays in controlling apple diseases, and to the development of a treatment calendar for each general material. From Entomology also are several distinct contributions: first, in the study of the life history of the codling moth with particular reference to control other than that now secured through the calyx spray; secondly, through additions to our knowledge of the life history of scale insects; and finally, in a study of the possible injurious effect of Scalecide, a type of miscible oil. In the latter case, contrary to expectations, anticipated injury has not yet materialized.

Of significant service to the fruit growing interests of the State has been the work of the Department of Agricultural Economics in studies on the costs of marketing apples. A manuscript giving complete report on this subject was submitted just as the year was drawing to a close, and will be published in the fairly near future.

Vegetable Gardening.

The research work of the Market Garden Field Station was seriously disorganized during the year by the transfer of the plant from Lexington to Waltham. Little could be done in the way of following up regular projects from the Field Station. However, the work of the Department of Entomology on the control of the squash vine borer is a distinct and valuable contribution to the vegetable growing industry of the State. An insect causing serious economic loss, which formerly was practically uncontrollable, can now be controlled. By-products of this investigation were the discovery of the possible role of nicotine as an ovicide, and work initiated for the purpose of activating nicotine and in this way enabling our growers to secure better results at lower costs. The work of this same department on control of the destructive onion thrips, and of the Department of Botany on control of onion smut are both important contributions to our vegetable growing industry.

During the year a cooperative agreement was entered into with the Bureau of Plant Industry of the United States Department of Agriculture, having for its objective the determination of the relation between varieties of sweet corn and time of planting, to susceptibility to corn borer attack. The project contemplates at least three years of observation before the facts of the case may be considered as having been even indicated.

The Cranberry Industry.

The two outstanding services of the Cranberry Station have been its contribution to our scientific and practical knowledge regarding the control of injurious insects, and its work with reference to frost predicting. In the former activity the results of twelve years' work are being brought together in a single manuscript, which will probably be offered for publication during the coming year. In the latter, organization has been perfected through which frost warnings are distributed by telephone throughout the cranberry growing section, at the expense of the cranberry growers. It is also planned to get out a forecasting manual for the growers, through which, by the use of data taken on their own bogs, they may predict the probability of local frosts with at least a fair degree of accuracy.

Work was continued on the blueberry investigation started some years ago in cooperation with the United States Department of Agriculture. A system of pruning the bushes was inaugurated with gratifying results. The plantation is continually being improved and the crop of the past year was the largest which we have as yet secured.

Poultry Husbandry.

The main projects in poultry husbandry are continuing ones, and in no one year can results be said to be particularly outstanding. Gains already made in breeding for high production were maintained; there was a decrease in mortality in the laying flock; through the granting of additional clerical help, much of the material collected through the past eleven years has been analyzed and submitted for publication. The new equipment granted by the State has been of immense assistance in enabling the Station to carry on this work in an effective and thoroughgoing way.

The cooperation of the Department of Veterinary Science in carrying forward research projects with reference to diseases of our domestic poultry and in making diagnoses showing the cause of death have been of great assistance. Likewise the work being done by this department in the administration of the law to reduce or eliminate certain poultry diseases is of very definite service to the Massachusetts poultry industry. Through the work thus carried on it will shortly be possible for Massachusetts poultrymen to purchase hatching stock and day-old chicks from known sources practically disease free. The work done under this law has been increasing annually. The record of number of birds tested and percentage of infection found in the testing work of the last four seasons is as follows:

Year.	Number of Birds Tested.	Percentage of Infection Found.
1920-21	24,718	12.50
1921-22	29,875	12.65
1922-23	33,602	7.60
1923-24	59,635	6.53

The number of disease-free flocks found increased from 25 in 1920-21 to 38 in 1923-24.

Soil Fertility and Plant Growth.

Many different departments of the Experiment Station contribute to work on this subject. Basic studies are being made by the Departments of Plant and Animal Chemistry and of Microbiology; the Department of Botany is carrying on a study relative to effective control of light, particularly in greenhouse culture; and the Department of Agronomy is initiating field experiments on a large scale. The new work started during the year includes a study of crop effect and rotation problems with reference to the onion and tobacco industries of the Valley. Of necessity work such as this must be carried on in a long-time project.

Tobacco Growing.

The newly organized research work on tobacco is just completing its second season. An outstanding result is indication of the depressing effect of timothy cover crop on yield and quality of the tobacco crop. This result is contrary to prevalent ideas on the subject, but is confirmed by three years' work carried on on the Tillson Farm. It warrants further investigation. Most of this newly organized field work is under the supervision of the Department of Agronomy.

The Department of Botany completed its work on wildfire during the year. The seed-bed treatment developed at this Station in cooperation with the Connecticut Station has proven to be at least fairly effective in controlling this most destructive disease. The possibility of extensive field infestation depends mainly on weather conditions. No successful field control has yet been developed; and in view of the uncertainties as to its need would probably not be widely utilized by growers even if developed.

Continued work of the Department of Botany at Tillson Farm has shown the depressing effect of lime on tobacco, particularly in a field infested with black root-rot. The timothy cover crop failed to remedy this condition, despite the fact that it was supposed to be effective in this way.

The new equipment granted by the Legislature of 1923-24 has enabled the Station to carry on this comparatively new work much more efficiently than could otherwise have been possible.

CATALOG OF EXPERIMENT STATION PROJECTS.

The list of projects in force as of January 1, 1925, and the industries of the State to which these projects apply, together with names of project leaders, are shown in the following table:

CATALOG OF ACTIVE PROJECTS, JANUARY 1, 1925.

Project Number, Title and Leader	Fruit Production	Tobacco Growing	Vegetable Gardening	Crop Protection	Soil Fertility and Plant Growth	Animal Husbandry	Poultry Husbandry	Agricultural Economics	General Field Crops
	Service of Project								
Agricultural Economics									
7 Boston food supply study. Professor McFall	...	...	...	...	...	...	...	*	...
8 Study of the costs of marketing apples. Assistant Professor Jefferson	*	...	...	...	...	...	...	*	...
Agronomy									
1 Investigation of the value of Hubam or annual sweet clover as compared to the biennial clovers. Professor Michels	...	...	...	...	*	*	...	...	*
2 Tobacco cropping system investigation. Assistant Professor J. P. Jones and Professor Anderson	...	*	...	...	*	...	...	...	...
3 Soil fertility studies on the South Soil Test. Assistant Professor J. P. Jones	...	...	...	...	*	...	...	...	...
4 Study of residual effects of fertilizers. Assistant Professor J. P. Jones	...	...	...	...	*	...	...	...	...
5 A field study of tobacco production in Massachusetts. Professor Beaumont	...	*	...	...	...	...	...	...	...
Botany									
1 Optimum conditions of light for plant resposse. Assistant Professor Clark	...	...	*	...	*	...	...	...	...
3 Tobacco investigations. (A study of soil reactions as a means for control of root rots of tobacco; also study of effects of soil reaction alone on the growth and development of tobacco.) Professor Osmun and Professor Anderson	...	*	...	*	*	...	...	...	...
5 Experimental spraying for control of cucumber mildew under glass. Assistant Professor Doran	...	...	*	*	...	...	...	...	...
6 Investigation of onion diseases. Professor Osmun and Professor Anderson	...	...	*	*	...	...	...	...	...
9 Investigation of a carrot blight. Assistant Professor Doran	...	...	*	*	...	...	...	...	...
13 Ecological study of pasture vegetation. Professor Osmun and Director Haskell	...	...	...	...	*	*	...	...	...
14 Investigation on control of tobacco wildfire. Professor Anderson	...	*	...	*	...	...	...	...	...
16 Relation of soil character to occurrence of onion smut. Professor Anderson	...	...	*	*	*	...	...	...	...
17 Study of the apple black rot control and the dusting schedule. Assistant Professor Doran.	*	...	...	*	...	...	...	...	...
18 Control of diseases of greenhouse vegetables. Assistant Professor Doran	...	...	*	*	...	...	...	...	...
Plant and Animal Chemistry									
4 Record of the Station herd. Professor Lindsey	...	...	...	...	...	*	...	...	...
14 A study of the availability of soil potash, with the object of developing a system of diagnosis for soils of the State. Professor Morse	...	...	...	...	*	...	...	...	...
17 Investigation of the role of physical condition in artificial feeds for calves. Assistant Professor Archibald	...	...	...	...	...	*	...	...	...
19 The value of inorganic calcium phosphate in the promotion of growth and milk production. Professor Lindsey and Assistant Professor Archibald	...	...	...	...	...	*	...	...	...

CATALOG OF ACTIVE PROJECTS, JANUARY 1, 1925.—*Continued.*

Project Number, Title and Leader		Service of Project: Fruit Production	Tobacco Growing	Vegetable Gardening	Crop Protection	Soil Fertility and Plant Growth	Animal Husbandry	Poultry Husbandry	Agricultural Economics	General Field Crops
Plant and Animal Chemistry—Continued										
20	A study of the fundamental factors affecting the suspension, adhesiveness, toxicity and general efficiency of copper fungicides. Professor Holland and Mr. Gilligan	...	...	...	*	...	...	...	...	...
21	Study of nitrogen fixation in the presence of, or as the result of, growth of legumes versus non-legumes under certain defined agronomic conditions. Professor Morse	...	...	...	...	*	...	...	...	...
22	Determining the nutritive value of hydrolized sawdust. Professor Lindsey and Assistant Professor Archibald	...	...	...	...	...	*	...	...	...
23	Study of the coloring matter in cranberries. Professor Morse and Professor Chenoweth	*	...	...	...	...	...	...	...	...
Cranberry Station										
1	Injurious and beneficial insects affecting the cranberry. Professor Franklin	*	...	...	*	...	...	...	...	...
2	Cranberry disease work. (Co-operative, U. S. D. A.) Professor Franklin	*	...	...	*	...	...	...	...	...
3	Weather observations with reference to frost prediction. (Co-operative, U. S. D. A.) Professor Franklin	*	...	...	...	...	...	...	...	...
5	Blueberry investigations. (Co-operative, U. S. D. A.) Professor Franklin	*	...	...	...	...	...	...	...	...
6	Cranberry bud development investigation. Mr. Lacroix	*	...	...	...	...	...	...	...	...
Entomology										
4	Control of the squash vine borer. Assistant Professor Worthley	...	...	*	*	...	...	...	...	...
5	Control of the squash bug. Assistant Professor Worthley	...	...	*	*	...	...	...	...	...
9	Number of generations of codling moth in Massachusetts and whether spraying for a second generation is advisable. Assistant Professor Bourne	*	...	...	*	...	...	...	...	...
10	Dates of hatching of scale insects and when to spray for them. Assistant Professor Bourne	*	...	...	*	...	...	...	...	...
12	Determination of best strength of lime-sulfur. Assistant Professor Bourne	*	...	...	*	...	...	...	...	...
13	Study of possible injurious effects of Scalecide on trees. Assistant Professor Bourne	*	...	...	*	...	...	...	...	...
14	Does spraying orchards kill bees? Assistant Professor Worthley	*	...	...	...	...	...	...	...	...
15	A study of the factors influencing the efficiency of nicotine in dusts and spray mixtures. Assistant Professor Worthley	*	...	*	*	...	...	...	...	...
16	Investigation of materials which promise value in insect control. Assistant Professor Bourne	*	*	*	*	...	...	...	...	...
17	Control of onion thrips. Assistant Professor Bourne	...	...	*	*	...	...	...	...	...
Farm Management										
1	Investigation of farm organization and labor efficiency on Massachusetts farms. Professor Foord	...	...	...	...	...	*	...	*	*
2	A study to determine the competitive status of the more important agricultural enterprises of Massachusetts. Assistant Professor Abell	...	...	...	...	...	*	...	*	*

Market Garden Field Station										
7	Study of the factors influencing heading of greenhouse lettuce. Assistant Professor Tiedjens	...	...	*	...	...	...	...	...	...
8	Study of conditions affecting the production and vegetative propagation of Washington asparagus. Assistant Professor Tiedjens	...	...	*	...	...	...	...	...	...
9	Investigation of susceptibility to corn borer attack of varieties of sweet corn as influenced by time of planting. (Co-operative U. S. D. A.) Mr. Dempsey	...	...	*	*	...	...	...	...	...
10	Variety improvement through seed and root selection: a. The improvement of beets (*Beta vulgaris*) through selection of roots and seed production. b. The improvement of carrots (*Daucus carota*) through selection of roots and seed production. Assistant Professor Tiedjens	...	...	*	...	...	...	...	...	...
Microbiology										
2	Soil fertility as influenced by micro-organisms in their relation to the presence and disappearance of organic matter. Assistant Professor Werkman	...	...	...	...	*	...	...	...	...
Pomology										
1	Study of interrelation of stock and scion in apples. Professor Shaw and Mr. Bailey	*	...	...	...	...	...	...	...	...
2	Study of the tree characters of fruit varieties. Professor Shaw and Mr. A. P. French	*	...	...	...	...	...	...	...	...
3	The genetic composition of peaches. Professor Shaw and Mr. Bailey	*	...	...	...	...	...	...	...	...
5	Comparison of cultivation and sod mulch in a bearing orchard. Professor Shaw	*	...	...	...	*	...	...	...	...
6	Comparison of clover sod and grass in sod mulch orchard. Professor Shaw	*	...	...	...	*	...	...	...	...
7	Test of fertilizers in a sod mulch orchard. Professor Shaw	*	...	...	...	*	...	...	...	...
8	Test of cover crops for apple orchards. Professor Shaw	*	...	...	...	*	...	...	...	...
9	Testing methods of pruning: a. An experiment in pruning apples b. Test of pruning methods on the Northern Spy and other varieties. Professor Shaw	*	...	...	...	...	...	...	...	...
12	Apple variety fruit spur study. Professor Shaw, Assistant Professor Drain and Assistant Professor C. P. Jones	*	...	...	...	...	...	...	...	...
13	Study of varieties of tree fruits. Professor Shaw and Mr. Raleigh	*	...	...	...	...	...	...	...	...
14	Study of the relation of winter injury of brambles to differential fertilization with potash salts. Professor Shaw, Assistant Professor C. P. Jones and Assistant Professor Clark	*	...	...	...	*	...	...	...	...
15	Orchard fertilization. Professor Shaw	*	...	...	...	*	...	...	...	...
16	Test of different amounts of nitrate of soda. Professor Shaw and Assistant Professor Drain	*	...	...	...	*	...	...	...	...
17	A study of the cultivation of the high bush cranberry (*Viburnum opulus*). Professor Shaw	*	...	...	...	*	...	...	...	...
18	Comparison of cultivation and heavy mulching for apples and pears. Professor Shaw	*	...	...	...	*	...	...	...	...
19	A study of the effects of fertilizer limitation on fruit plants. Professor Shaw	*	...	...	...	*	...	...	...	...
20	Test of fertilizers for pears. Professor Shaw	*	...	...	...	...	...	...	...	...
21	Study of fruit harvesting and storage. Mr. Raleigh	*	...	...	...	...	...	...	...	...
Poultry Husbandry										
1	Broodiness in poultry. Professor Hays	...	...	...	...	...	...	*	...	...
2	Breeding poultry for egg production. Professor Hays	...	...	...	...	...	...	*	...	...
3	A genetic study of Rhode Island Red color. Professor Hays	...	...	...	...	...	...	*	...	...
4	Determination of genetic laws governing results in inbreeding of poultry. Professor Hays	...	...	...	...	...	...	*	...	...
5	The hatchability of eggs. Professor Hays	...	...	...	...	...	...	*	...	...

CONTROL SERVICE.

In addition to carrying on investigations, the Experiment Station is required to perform certain control and regulative functions, as follows:

1. Inspection of commercial fertilizers.
2. Inspection of commercial feed stuffs.
3. Inspection of machinery and glassware used in the testing of dairy products.
4. Elimination of white diarrhoea in poultry.

Reports on all except the third of these are published separately, respectively in control bulletins Nos. 29 and 30, 28, and 27 of the Experiment Station.

The work of the year under the law providing for the inspection of dairy glassware is summarized below:

Certificates of proficiency awarded	42
Machines and apparatus inspected by Mr. Howard, November and December, 1924	117 places
Machines condemned	3
Minor repairs ordered on machines	14
Necessary re-inspections	4
Glassware calibrated	5,092 pieces
Glassware condemned	11 pieces

GENERAL ANALYTICAL AND DIAGNOSTIC WORK.

Since its very beginning the Experiment Station has been called upon to perform a large amount of miscellaneous diagnostic and analytical work. Diseased plants, specimens of insect injury, dead birds, and other materials are sent in for diagnosis. Soils, feeds, fertilizers, insecticides and fungicides, samples of milk and cream, the alimentary tract of animals supposedly poisoned, and many other things are submitted for analysis. Formerly this work was done free of charge. There is no doubt that this policy of making free diagnosis and analysis had great educational value. In recent years, however, the burden on the research forces of the Experiment Station has been increasingly great. This, together with the significant fact that many samples are submitted out of mere curiosity rather than on the basis of definite need for service, led to the imposition of a fee for performing the greater part of this work, exceptions being diagnoses of plant disease and insect injury. As a result, there has been a significant decrease in the amount of service requested. There has been criticism of the practice of making charges for this miscellaneous work. Many farmers and farm organizations feel that the Experiment Station is not now giving the service which it formerly did. It should be remembered, however, that because of reducing its activities in this direction the Station is able to do more work in the study of problems of vital significance to Massachusetts agriculture. Other than as above mentioned, this phase of the year's work does not differ markedly from that of other years.

ADVANCED REGISTRY TESTING OF PURE BRED COWS.

This work was started in 1902 on a very small scale. The work is operated on the basis of a revolving fund, and has no financial support from the State. Up to three years ago, a rather general and consistent increase was shown year by year. Owing probably to the current depression in agriculture with consequent diminished demand for pure bred stock, tne work this past year was somewhat less than in the immediately preceding years. The following table shows the more important operations of the period in question:

SUMMARY OF TWO-DAY WORK, DECEMBER, 1923, THROUGH NOVEMBER, 1924.

Number of Cows Tested.

Month	Number of Supervisors Whole or Part Time	Guernsey	Jersey	Ayrshire	Shorthorn	Holstein	Totals
December	9	214	102	70	22	97	505
January	10	250	91	71	21	89	522
February	13	251	98	79	17	75	520
March	9	251	94	85	14	92	536
April	11	252	93	101	13	93	552
May	10	259	91	102	13	97	561
June	10	237	85	95	11	80	508
July	10	243	76	99	11	69	498
August	11	262	89	97	10	61	519
September	11	247	101	95	9	64	516
October	10	249	101	101	6	66	523
November	10	248	90	92	11	68	509
Totals	—	2963	1111	1087	157	951	6269

Number of Herds Visited.

Month	Number of Supervisors Whole or Part Time	Guernsey	Jersey	Ayrshire	Shorthorn	Holstein	Totals
December	9	35	15	7	2	10	69
January	10	38	13	8	2	11	72
February	13	40	13	9	2	13	77
March	9	41	12	7	2	10	72
April	11	39	11	10	1	11	72
May	10	42	11	8	1	13	75
June	10	41	12	9	1	13	76
July	10	41	13	8	1	11	74
August	11	43	12	7	1	11	74
September	11	40	13	8	1	11	73
October	10	38	14	7	1	11	71
November	10	38	13	7	1	12	71
Totals	—	476	152	95	16	137	876

The above compares with a total of 6270 tests for the year ending December 1, 1923. The number of cows on yearly test decreased in one year from 520 to 509; the number of farms visited remained practically the same.

HOLSTEINS. There were 10 men employed for seven-day work, 19 farms visited, and 86 reports turned in.

CHANGES IN STAFF

The changes in staff during the year are shown in the following table:

	Resignations	*Position*	*Appointments*	
		Analyst, Feed and Fertilizer Control	George B. Dalrymple	Jan. 1.
Jan. 15.	Harold F. Tompson	In Charge, Market Garden Field Station		
Mar. 31.	Charles O. Dunbar	Investigator in Chemistry	Gerald M. Gilligan	July 1.
June 30.	Robert L. Coffin	Investigator in Agriculture		
Aug. 1.	Anna M. Wallace	Curator in Botany	Gladys I. Miner (transfer)	Aug. 1.
		Technical Assistant, Department of Veterinary Science	James J. McDermott	Aug. 1
Sept. 1.	Arao Itano	Assistant Professor in Microbiology	Chester H. Werkman	Sept. 1.
Oct. 31.	Hazel Parker	Analyst, Poultry Disease Elimination	Alice Norcross	Oct. 27.
Nov. 1.	O. S. Flint	Analyst Poultry Disease Elimination (new title, Specialist)	Patrick E. Bransfield	Nov. 1.
Nov. 12.	Henry S. Green (retired)	Librarian	Basil B. Wood	Nov. 12.
Nov. 30.	Harold E. Wilson	Laboratory Assistant in Pomology		
		Investigator in Botany	Theodore T. Ayers	Nov. 16.
		Microscopist, Feed Control	F. A. McLaughlin	

PUBLICATIONS OF THE YEAR.

Annual Report.

Thirty-sixth annual report with index.

Bulletins.

No. 219. Combating Apple Scab, by William L. Doran and A. Vincent Osmun.

No. 220. Correlation Studies on Winter Fecundity, by F. A. Hays, Ruby Sanborn and L. L. James.

Bulletins, Technical Series.

No. 6. The Inheritance of Fertility and Hatchability in Poultry, by F. A. Hays and Ruby Sanborn.

Bulletins, Popular Edition.

No. 6. The Inheritance of Fertility and Hatchability in Poultry, by F. A. Hays and Ruby Sanborn.

Bulletins, Control Series.

No. 27. Control of Bacillary White Diarrhoea, 1923-24, by G. E. Gage and O. S. Flint.

No. 28. Inspection of Commercial Feedstuffs, by Philip H. Smith and Frank J. Kokoski.

No. 29. Inspection of Commercial Fertilizers, by H. D. Haskins, L. S. Walker and G. B. Dalrymple.

No. 30. Inspection of Lime Products used in Agriculture, by H. D. Haskins, L. S. Walker and G. B. Dalrymple.

Meteorological Reports.

Nos. 421-432, inclusive.

Scientific Contributions.

No. 19. The Biology of Trichopoda Pennipes Fab., a Parasite of the Common Squash Bug, by Harlan N. Worthley. In Psyche, Vol. 31, Nos. 1 and 2, February and April, 1924.

No. 22. Oxidase Activity in Varieties of Apples, by Brooks D. Drain. In Proceedings of the American Society for Horticultural Science, 1923.

No. 23. The Effect of Sodium Hydroxide on the Composition, Digestibility and Feeding Value of Grain Hulls and Other Fibrous Material, by J. G. Archibald. In Jour. Agr. Research, Vol. XXVII, No. 5, February 2, 1924.

No. 25. The Loss of Calcium Carbonate in Drainage Waters as Affected by Different Chemical Fertilizers, by F. W. Morse. In Soil Science, Vol. XVII, No. 3, March, 1924.

No. 26. The Problem of Pastures in Semi-Waste Lands of New England, by S. B. Haskell. In Jour. Amer. Soc. Agron., Vol. 16, No. 3, March, 1924.

No. 27. Overwintering of Tobacco Wildfire in New England, by P. J. Anderson. In Phytopathology, Vol. XIV, No. 3, March, 1924.

No. 28. Adsorption and Absorption of Bases by Soils, by C. P. Jones. In Soil Science, Vol. XVII, No. 3, March, 1924.

No. 29. The Higher Cost of Food in Massachusetts, by R. J. McFall. In Quarterly Publication, American Statistical Association, Sept., 1924.

No. 31. Stimulation of Plant Growth by Means of Electric Lighting, by Victor A. Tiedjens. A paper presented before the Eighteenth Annual Convention of the Illuminating Engineering Society, October, 1924.

METEOROLOGICAL OBSERVATION.

Department of Meteorology.

PROF. J. E. OSTRANDER, HEAD

ANNUAL SUMMARY FOR 1925.

PRESSURE (IN INCHES)

Maximum reduced to freezing	30.44 Jan. 2nd, 9 A.
Minimum reduced to freezing	28.88, Dec. 13th, 7 P.
Maximum reduced to freezing and sea-level	30.77, Jan. 2nd, 9 A.
Minimum reduced to freezing and sea-level	29.19, Dec. 13th, 7 P.
Mean semi-daily reduced to freezing and sea-level	30.010
Annual range	1.58

*AIR TEMPERATURE (IN DEGREES FAHR.)

Highest ....97.0, Aug. 7th, 1 :00 P.
Lowest ....-8.0, Jan. 27th 6 :00 A. Jan. 28th, 6 :00 A.
Mean hourly 46.6
Mean of means of max. and min 46.7
Mean sensible (wet bulb) 41.0
Annual range 105.0
Highest mean daily ....78.8, Aug. 7th
Lowest mean daily ....-0.3, Jan. 27th.
Mean maximum 57.8
Mean minimum 35.7
Mean daily range 22.1
Greatest daily range..43.5, Oct. 23rd., 24th.
Least daily range ....3.0, Feb. 5th.

HUMIDITY

Mean dew point 36.4
Mean force of vapor 362
Mean relative humidity 73.9

WIND

Prevailing direction ....West

Summary

North ....10 per cent
North Northeast .... 9 per cent
South .... 9 per cent
South Southwest ....19 per cent
Northwest .... 9 per cent
Other directions ....41 per cent
Total movement ....53.855 m
Greatest daily movement..553m., Mar. 12th
Least daily movement.....22 m., Dec. 12th
Mean daily movement..............147 m
Mean hourly velocity ....6.1 m
Maximum pressure per square foot, 23.5 lbs., =69 m. per hour, Apr. 14th, 3 P., N. W.
Maximum velocity for 5 minutes, 42 m. per hour, July 13th, 1 P., S. W.

*Temperature in ground shelter.

PRECIPITATION (IN INCHES)

Total precipitation, rain or melted snow 30.96
Snow total in inches 45.0
Number of days on which .01 or more rain or melted snow fell 96

WEATHER

Mean cloudiness observed ......41 per cent
Total cloudiness recorded by Sun Thermometer ......1637 hrs.=37 per cent.
Number of clear days 141
Number of fair days 145
Number of cloudy days 80

BRIGHT SUNSHINE

Number of hours recorded, 2838 hrs.=63 per cent.

DATES OF FROSTS

Last ....May 2d
First ....Sept. 24th

DATES OF SNOW

Last ....April 8th
First ....Nov. 9th
Total days of sleighing 54

GALES OF 50 OR MORE MILES PER HOUR

Jan. 1st, 58m, N. W.; 11th, 67m, S.S.E.; 21st, 63m, N.W.; 26th, 56m, N.W.

Mar. 11th, 57m, N.E.; 12th, 63m, N.N.E.; 28th, 59m, W.N.W.

Apr. 14th, 69m, N.W.; 51m, 24th, N.N.W.

May 18th, 52m, S.

July 13th, 56m, S.W.

Nov. 17th, 55m, N.N.W.

REPORT OF THE TREASURER

F. C. KENNEY

United States Appropriation, 1923-24.

Dr.	Hatch Fund.	Adams Fund.
To receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1924, under acts of Congress approved March 2, 1887 and March 16, 1906	$15,000.00	$15,000.00

Cr.

Adams:	
By salaries	$15,000.00
Hatch:	
By salaries	$15,000.00

State Appropriations, 1923-24.

Cash balance brought forward from last fiscal year	$119,790.75
Cash received from State Treasurer	40,733.93
fees	9,710.88
sales	393.54
miscellaneous	
	$170,629.10

Cash paid for salaries	$73,870.99
labor	19,015.27
stationery and office supplies	666.31
scientific supplies	2,770.72
feed	1,254.71
seeds, plants and sundry supplies	3,151.64
fertilizers	1,502.08
communication service	1,021.94
traveling expenses	5,929.08
transportation of things	862.98
publications	2,262.23
heat, light, water and power	1,240.26
furniture and fixtures	767.36
library	1,163.99
scientific equipment	633.49
livestock	—1,606.16
tools and machinery	2,264.09
buildings and land	3,001.98
contingent	17.79
remitted to State Treasurer	50,838.35
	$170,629.10

MASSACHUSETTS

AGRICULTURAL EXPERIMENT STATION

BULLETIN No. 219 JANUARY, 1924

COMBATING APPLE SCAB

Spraying and Dusting Experiments in 1923 with Summary of Three Years' Results

By WILLIAM L. DORAN and A. VINCENT OSMUN

Recently completed studies on apple scab and its control show that development of this disease may be prevented through the use of a number of different materials — lime-sulfur, dry lime-sulfur, or copper sprays followed by lime-sulfur, may be effectively used, as also dusts of various kinds. Scab development is governed largely by weather conditions; possibility of successful control, by the proper timing of protective treatment and efficiency in the actual spraying and dusting work. These facts are brought out in this bulletin, which is the final report of a three-year investigation. Tabulated results of the work carried on in 1923 are presented, likewise a summarization of all data collected during the course of the study.

Publication of this Document approved by the Commission on Administration and Finance

Requests for Bulletins should be addressed to the

AGRICULTURAL EXPERIMENT STATION

AMHERST, MASS.

COMBATING APPLE SCAB.

SPRAYING AND DUSTING EXPERIMENTS IN 1923[1] WITH SUMMARY OF THREE YEARS' RESULTS.

By William L. Doran and A. Vincent Osmun.

Introduction.

Scab has long been a disease to reckon with in the apple orchards of Massachusetts, but not until the advent and extensive planting of the McIntosh, a variety particularly susceptible to attack by the scab fungus, did it become a menace of large proportions. As more and more of the McIntosh orchards came into bearing, an increasing number of growers experienced difficulty in controlling the disease and losses became so large as to seriously threaten the orchard industry. Finally, in 1920, appeal was made to the Station by the growers, and in the fall of that year the Station entered into a cooperative agreement with the Nashoba Fruit Producers' Association under which experiments on the control of scab were planned and undertaken by the Department of Botany.

The results of the spraying and dusting experiments of the first two seasons already have been reported by Krout (1) (2).[2] The present report is on the work of 1923, together with such references to the work in Massachusetts in 1922 and 1921 as will assist in making points clear. The results of the three years' experiments are summarized in Table III (page 17). Other references in this report are for the most part to spraying and dusting experiments conducted within the last two years, especially in the northeastern states.

The general objectives of the investigations in 1923 were to secure more light on the following questions in regard to the control of apple scab:

1. What is the effect of the addition to the spray schedule of a prepink application?
2. How does dry lime-sulfur compare with liquid lime-sulfur in fungicidal efficiency?
3. What is the ratio of dry lime-sulfur to water, at which this fungicide is dependable?
4. What is the effect of the addition of calcium caseinate spreader to the fungicide when applied as a dust and as a spray?
5. How does a spray schedule consisting of lime-sulfur throughout the season compare with a schedule in which Bordeaux mixture is substituted for the application or applications before flowering?
6. How does Atomic Sulphur compare with dry and liquid lime-sulfur for the control of scab?
7. Does the addition of lime or of calcium caseinate to the combination lime-sulfur-lead arsenate spray improve the mixture?
8. For the control of apple scab, what is the fungicidal efficiency of sulfur dust? What is the effect of substituting a copper-lime-arsenic dust for the prepink and pink applications?

The rainy summer of 1922 was especially suitable for the experimental work, because of the abundant infection on unsprayed trees. The summer of 1923 was much drier; there was a rainfall of only 7.29 inches in May, June and July, as compared with 20.14 inches in the same period in 1922. This naturally resulted in less infection, but there was sufficient infection on unsprayed trees in every case but one to justify the drawing of conclusions as to the relative values of the several treatments applied.

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[1] The experiments here described were conducted in the orchards of Harry L. Knights of Littleton, H. L. Frost of Littleton, Stephen W. Sabine of Groton, and A. N. Stowe of Hudson. The superintendents of these orchards are Roy C. Wilbur of the Frost Farm, John J. Collins of the Stowe Farm, and J. W. Ames of the Knights Farm. Acknowledgment is due these men for placing their orchards at the disposal of the Experiment Station, and for cooperating in the investigations. Acknowledgment is also due to the Nashoba Fruit Producers' Association for their cooperation.

[2] Numbers in parenthesis refer to literature cited, see page 13.

The results, as given in tables I and II, and in the text, are expressed in percentage of scabby apples present in the check and in each sprayed or dusted plot. In interpreting the results of any spraying or dusting experiments, the percentage of infection in the check is of primary importance. If this is low, the data are correspondingly of less value, since it cannot be said that the fungicidal treatment was put to a real test. The percentage of infection on the unsprayed trees in the Sabine orchard where some of the spraying experiments were conducted was so low that the results in that orchard are not considered in this report.

Methods and Materials Used.

The trees used for these experiments were of the McIntosh variety. Each orchard was divided in such a way that the check plot was as nearly as possible like the treated plots in every way except fungicidal treatment received. The check plots received no treatment for scab control, but did receive a calyx application with insecticides only. All check plots were surrounded by or contiguous to the treated plots. In dividing an orchard for a dusting experiment, it is difficult to so locate the check plot that it will not receive some dust as the dust drifts through the orchard. If it were possible to prevent this entirely, the percentage of scabby fruits on the dust checks would probably be larger.

The following treatments were tested or compared:

1. Dry lime-sulfur 3–50 for the pink, calyx and one later application.
2. Dry lime-sulfur 3–50 with calcium caseinate added for the pink, calyx, and one later application.
3. Dry lime-sulfur 2–50 for the pink, calyx and one later application.
4. Dry lime-sulfur 4–50 for the pink, calyx and one later application.
5. Dry lime-sulfur 3–50 for the prepink, pink, calyx and one later application.
6. Bordeaux mixture 3–10–50 for the prepink and pink applications followed by liquid lime-sulfur 1–50 for the calyx and one later application.
7. Bordeaux mixture 3–10–50 for the pink application followed by liquid lime-sulfur 1–50 for the calyx and one later application.
8. Atomic Sulphur for the pink, calyx and one later application.
9. Liquid lime-sulfur for the pink, calyx and one later application.
10. Bordeaux mixture 3–10–50 for the pink application followed by dry lime-sulfur 4–50 for the calyx, and one later application.
11. Liquid lime-sulfur with lime added for the pink, calyx and one later application.
12. Copper dust for the prepink and pink applications followed by sulfur dust for the calyx and two later applications.
13. Sulfur dust for the prepink, pink, calyx and two later applications.
14. Sulfur dust with calcium caseinate added for the prepink, pink, calyx and two later applications.

In one orchard, the dusting schedule began with the pink instead of the prepink application.

An examination of Tables I and II will show which treatment each of the thirty-five plots received, including the fungicide and its dilution used at each application, together with the date of each application.

Rates of Application.

About four gallons of spray per tree per application were used for trees twelve to fifteen years old. About one and one-half pounds of dust per tree of this size were used at each application.

Liquid lime-sulfur was used at the rate of one gallon in fifty gallons of water. Dry lime-sulfur was used at the rate of two, three or four pounds in fifty gallons; this is expressed in abbreviated form in the text as dry lime-sulfur 2–50, 3–50, etc. It was not found necessary to add water to this material before placing it in the spray tank; in fact, to do so resulted in increased lumpiness. A more satisfactory method is to sift this material into the nearly filled spray tank with the agitator running.

Calcium caseinate spreader (which is sold under various trade names, such as Kayso, Spracein, etc.) was used at the rate of 1 pound in 100 gallons, or it was added to sulfur dust so that the dust mixture would contain 5 per cent calcium caseinate.

The copper dust (used only before the flower buds opened) contained 11 per cent dehydrated copper sulfate. The sulfur dust contained 92 per cent sulfur and 8 per cent inert ingredients. When it was desired to apply an arsenical also to dusted trees, a dust containing sulfur and lead arsenate in the ratio 90:10 or 85:15 was used.

Arsenate of lead and nicotine sulfate (Black Leaf 40) in the usual proportions were added to the sprays for each application, except for the fourth summer spray when nicotine sulfate was omitted.

The spraying was done with power sprayers with about 200 pounds pressure, using Pilot rods or regular spray rods.

The dusting was done with power dusters, either Perfect or Niagara. The duster was driven along both sides of each row of trees, so that dust was applied to each tree from opposite sides. Dusting is not a pleasant operation, because of the pain caused by the sulfur getting into the eyes. Goggles, although somewhat of a nuisance, appear to be a necessity when much dusting is to be done. Some difficulty was experienced in thoroughly dusting the tops of tall trees. Krout (2) and Childs (3) both mention this. The tops of taller trees cannot be thoroughly coated with dust when any wind is blowing. The dusting was done early in the morning, beginning about five o'clock in most cases. The foliage was not always wet, however. There is no experimental evidence of the necessity of dusting only when the foliage is wet.

Friez hygro-thermographs and rain gauges were maintained in the Frost and Sabine orchards. The data on rainfall secured in the orchards is not considered complete, and the precipitation data given in this report are from the Concord observer for the United States Weather Bureau as recorded in Climatological Data for New England.

Because of the large yield of fruit, it was manifestly impossible to examine every apple in a plot at picking time. For this reason, four representative trees were selected from each plot for examination of the fruit. About 150,000 apples were examined. Since much of the infection was late, most of the scabby apples even on the check plots were marketable. Apples designated as scabby in the data include both marketable-scabby, and unmarketable scabby.

Effect of the Addition of a Prepink Application to the Schedule.

The delayed dormant application is made just as the buds are breaking or when the first tips of green show. The pink application is usually understood to mean that which is applied as soon as the blossom buds separate in the clusters, while they show pink, but before they begin to open. Any application of a summer-strength fungicide made between the delayed dormant and the pink applications may be spoken of as a prepink application. The interval between the prepink and pink applications, which will depend upon the weather and consequent rapidity of growth, is bound to be short. In the case of large orchards, there is likely to be no interval, so that an application begun as a prepink will end as a pink, as regards the development of the flower buds. The first summer application, either prepink or pink, should be made when the tree is first in danger of infection, that is, before the first discharge of winter spores from the dead leaves beneath the tree. It is probable that many of the failures to control apple scab in Massachusetts have occurred because this first summer spray was too long delayed. The prepink cannot be regarded as a substitute for the pink application. If a prepink application is necessary, a pink is none the less so, because new growth has exposed new and unprotected leaf surface to the danger of infection.

The beginning of the period when the tree is in danger of infection can be determined only by "trapping" the winter spores on adhesive-coated glass slides inverted over the dead leaves and microscopic examination of the slides, after the method described by Wallace (4) and Childs (5). In some years, winter spores are mature and ready to be discharged, if the dead leaves containing them are wet, while the apple buds are only beginning to swell. In such years, it is evident that if the first application is deferred until the flower buds show pink, some infection is likely to occur before that time. Because a prepink application is proved necessary or unnecessary one year, it does not follow that the reverse may not be true the next year. A prepink application made in the absence of information as to the development and condition of the winter spores is to be regarded as insurance.

Krout (2) in 1922 tested the addition of a prepink application to the spray schedule. In the first orchard, the addition of the prepink application was not followed by a decrease in the percentage of scab but rather by an increase of 3 per cent. In each of two other orchards the prepink spray apparently reduced the scab 1 per cent. It is evident, therefore, that in 1922 no real benefit from the use of the prepink spray was shown, as compared with a schedule which included only a pink application before the flowers opened.

In 1923, spray schedules with and without a prepink application were tested in two orchards. In the Frost orchard trees sprayed with lime-sulfur beginning with the pink application yielded 7.06 per cent scabby fruit and when this material was used beginning with the prepink application, there was only 1.2 per cent scab, a significant reduction. Where Bordeaux mixture was used for the pink application, followed by lime-sulfur for the later applications, there was 1.7 per cent scabby fruit, and on the plot where this schedule was modified by the addition of a prepink application of Bordeaux mixture, only 0.6 per cent scabby fruit was produced. Here again there was a reduction in the percentage of scab, although such a small one as to be probably without significance.

In the Knights orchard, trees sprayed with dry lime-sulfur 4–50 beginning with the pink application, yielded 1.7 per cent scabby fruit, and where dry lime-sulfur 3–50 was applied beginning with the prepink spray, there was 4.8 per cent scabby fruit. Since the strength of the material was different the addition of a prepink application was not the only changed factor affecting the control of the disease. When the cost of the material and the cost of the labor for each application are considered, however, it is evident that three applications of dry lime-sulfur 4–50 beginning with the pink were a more profitable treatment than four applications of dry lime-sulfur 3–50 beginning with the prepink. There was 1.06 per cent scabby fruit on the trees sprayed with Bordeaux mixture beginning with the pink application and dry lime-sulfur 4–50 for the later applications. As compared with this there was 4.9 per cent scabby fruit on trees sprayed with Bordeaux mixture for the prepink and pink applications followed by liquid lime-sulfur for the later applications. Since, as is shown elsewhere in this report, we may regard liquid lime-sulfur as of equal fungicidal efficiency with dry lime-sulfur 4–50, it is evident that the addition of a prepink application did not reduce the percentage of scab; instead, it was followed by an increase of 3.84 per cent. The need of a prepink application is not shown by the data of either 1922 or 1923.

When we consider dusting, however, the case may be entirely different. In the two orchards where the dusting schedule began with a prepink application, a good control of scab was secured. In the orchard where only one application, the pink, was made before the flower buds opened a much poorer control resulted. Satisfactory experimental evidence on this point, however, would necessitate that the two schedules, with and without a prepink application, be used in adjoining parts of the same orchard with one check for the two.

The Use of Dry Lime-Sulfur.

Arguments for and against the use of dry lime-sulfur as compared with the liquid form include, of course, considerations of the relative costs, convenience in handling, and effect on the pump. But the first question to consider is, does it control scab? For if it does not, further consideration is needless. In the experiments here described, trees sprayed with dry lime-sulfur 4–50, beginning with the pink application, produced an average of 1.3 per cent scabby apples as compared with 60.7 per cent on the unsprayed trees. In the same orchards, on trees sprayed with liquid lime-sulfur, the percentage of scabby apples was 2.7. The conclusion from this is that dry lime-sulfur is fully as dependable for the control of apple scab as is liquid lime-sulfur.

In two successive years, Krout (2) secured as good control of apple scab with dry lime-sulfur as with the liquid. Gardner (6) found dry lime-sulfur as effective as liquid lime-sulfur against apple scab. In most of the experiments of Keitt and Jones (7), the results with dry lime-sulfur in controlling apple scab were similar to those obtained with liquid lime-sulfur. Massey and Fitch (8) had practically the same results with dry as with liquid lime-sulfur.

Dry lime-sulfur is less bulky to transport. But the material necessary to make 100 gallons of spray costs about twice as much in the dry form as in the liquid. The so-called free sulfur in dry lime-sulfur does not redissolve in water, and this, according to Sears (9), wears out pumps and nozzles more rapidly than does liquid lime-sulfur. It may be added that if this objection is valid, it will hold none the less for dry-mix sulfur-lime, or any sulfur fungicide other than a solution. It seems that the orchardist must decide for himself whether to use dry or liquid lime-sulfur, but he may be sure that the fungicide in either form is efficient for the prevention of infection by the apple scab fungus.

Concentration at Which to Use Dry Lime-Sulfur.

Trees sprayed with dry lime-sulfur 4–50 yielded on the average 1.3 per cent scabby apples as compared to 60.7 per cent on unsprayed trees; while trees sprayed with dry lime-sulfur 2–50 and dry lime-sulfur 3–50 yielded 3.9 and 5.8 per cent scabby apples respectively, as compared to 67.6 per cent on unsprayed trees. The indications are that the use of less than 4 pounds of dry lime-sulfur in 50 gallons will be followed by a slight increase in the percentage of scabby apples.

Krout (2) secured similar results. The check plot yielded 41 per cent scabby fruit, the dry lime-sulfur 4–50 plot yielded 2 per cent, and the dry lime-sulfur 3–50 plot yielded 4 per cent scabby fruit. The difference was slight in 1922 as it is in 1923, but the variation is in the same direction.

Whether liquid or dry lime-sulfur is used, the protection afforded is dependent upon the amount of sulfur present in the diluted spray. The percentage of sulfur is of course not always the same in all dry lime-sulfurs. But in general it may be said that not less than 4 pounds of dry lime-sulfur in 50 gallons are required to supply the same number of pounds of sulfur as are present when 1 gallon of commercial concentrated lime-sulfur, of the usual strength tested in degrees Baumé, is diluted to 50 gallons. According to Dutton (10) the amount of dry lime-sulfur necessary to furnish the equivalent amount of sulfur in 50 gallons is 4.4 pounds, and according to Eustace and Pettit (11), it is 4.8 pounds.

The evidence submitted indicates that reducing the amount of dry lime-sulfur below 4 pounds to 50 gallons is a practice of doubtful economy.

Effect of a Calcium Caseinate Spreader on Control of Scab.

The percentage of scabby fruit was reduced slightly by the addition of calcium caseinate spreader to lime-sulfur. At Frost's, this reduction was from 7.06 to 5.08 per cent scabby fruit; and at Knights', the reduction was from 4.6 to 0.68 per cent. It is a question whether these reductions are in themselves large enough to be significant, but the results are consistently in favor of the use of the calcium caseinate.

The addition of calcium caseinate to sulfur dust did not result in a reduction in the percentage of scabby apples, as compared with the plots dusted with sulfur alone, in either the Frost or the Sabine orchard; and in the Stowe orchard the results were practically the same. In the Frost orchard, the addition of calcium caseinate spreader to sulfur dust was followed by a considerable increase in the percentage of scabby apples.

In the spreader tests of Stearns and Hough (12) the addition of calcium caseinate did not increase the effectiveness of the spray in protecting fruit and foliage from disease and insects. Keitt and Jones (7) secured slightly better control of scab when calcium caseinate was added to lime-sulfur than when the latter was used alone, but it was not considered that the commercial value of its addition was determined. Trees sprayed with lime-sulfur by Parrott, Stewart, and Glasgow (13) yielded 2.1 per cent scabby apples, while trees sprayed with lime-sulfur with calcium caseinate added yielded 4.8 per cent scabby apples. In the experiments of Massey and Fitch (8) trees sprayed with lime-sulfur yielded 1.2 per cent scabby apples, and those trees which were sprayed with lime-sulfur with calcium caseinate added yielded 1.1 per cent scabby apples. In their dusting experiments, trees which received sulfur yielded 2.6 per cent scabby apples and those which were dusted with sulfur with calcium cascinate added yielded 2.4 per cent scabby apples.

The claim is made that calcium caseinate spreaders improve the adhesiveness of sprays, but it should be noted that Butler and Smith (14) found that the adhesiveness of Bordeaux mixture is not affected by the addition of calcium caseinate. Whatever may be said in favor of the use of calcium caseinate, and there are sound arguments in its favor, it cannot be said that there is sufficient or satisfactory evidence as to its increasing the fungicidal efficiency of lime-sulfur against apple scab to a point of commercial importance. It is probable, however, that the more imperfect the spraying, the greater the benefit to be derived from the use of a calcium caseinate spreader.

Calcium caseinate is further considered in connection with its effect on compatibility of ingredients in combination sprays.

Bordeaux Mixture as Compared with Lime-Sulfur for Applications Before Flower Buds Open.

The Bordeaux mixture used in these experiments was an excess-lime Bordeaux mixture containing 3 pounds of copper sulfate and 10 pounds of lime in 50 gallons of water. This is referred to in the abbreviated language of practice as 3–10–50 Bordeaux mixture. It was used, rather than a Bordeaux mixture containing copper sulfate and lime in the ratio 1:1, because it has been found to be somewhat safer to the sprayed tree.

In the preparation of Bordeaux mixture, the diluted copper sulfate solution and the diluted milk-of-lime may be poured together into a third barrel or into a spray tank, and this is a method quite generally followed. But it requires some special equipment and involves unnecessary labor. It is important that at least one of the stock solutions, either copper sulfate or lime, be diluted before the other and concentrated one is added to it, but as Butler (15) has shown, it is not necessary that both be diluted before mixing. In practice, it is sufficient to place the copper sulfate stock solution in the spray tank when it is about three-fourths full of water; then, with the agitator running, add the undiluted stock solution of the lime, and fill the tank with water. The Bordeaux mixture used in these experiments was prepared in this way.

In many experiments where Bordeaux mixture and lime-sulfur have been compared, it has been found that the former has a somewhat greater fungicidal efficiency than the latter against apple scab. Unfortunately, Bordeaux mixture usually burns the fruit and foliage of the apple. The results of many experiments are well illustrated by those of Krout (2) who found that even an excess-lime Bordeaux mixture of 3–10–50 formula, when used for all applications, russeted the fruit and burned the foliage severely. For this reason, the use of Bordeaux mixture throughout the spraying season was not attempted in 1923. It was, however, used on certain plots for the pink, or the prepink and pink applications, followed by lime-sulfur for later applications.

The plot in the Frost orchard which received three applications of liquid lime-sulfur yielded 2.1 per cent scabby apples, while the plot which received Bordeaux mixture for the pink application and liquid lime-sulfur for the calyx and last applications yielded 1.7 per cent scabby apples. This is too small a difference to have any significance. The plot which received the prepink and pink applications of Bordeaux mixture followed by liquid lime-sulfur for the later applications yielded 0.6 per cent scabby fruit. This reduction in the amount of scabby fruit cannot be attributed entirely to the substitution of Bordeaux mixture for lime-sulfur since this plot received one extra application; namely, the prepink. The results in Frost's orchard do not show that any benefit is to be derived from the substitution of Bordeaux mixture for lime-sulfur for the early application.

At the Knights orchard, Bordeaux mixture was substituted for dry lime-sulfur in one case and for liquid lime-sulfur in another for the pink or prepink and pink applications. The plot sprayed with dry lime-sulfur throughout the season yielded 1.7 per cent scabby fruit, and the plot on which Bordeaux mixture was substituted for dry lime-sulfur at the time of the pink application yielded practically the same; namely, 1.06 per cent scabby fruit. No benefit from the substitution of Bordeaux was proved in this case. The plot sprayed with liquid lime-sulfur throughout the spraying season beginning with the pink application produced a slightly smaller percentage of scabby apples than did the plot which received Bordeaux mixture at the prepink and pink applications followed by liquid lime-sulfur for the calyx and fourth summer spray.

We have no evidence at either of these orchards that Bordeaux mixture is preferable to lime-sulfur for the prepink and pink applications. The labor involved in preparing Bordeaux mixture is sufficient to swing the scale against it in the absence of more evidence in its favor.

Dr. O. R. Butler states (in correspondence) that in his experiments in New Hampshire in 1922 where a spray schedule of lime-sulfur alone was followed, there was 67.5 per cent scabby fruit; while the substitution of Bordeaux mixture for the pink application reduced the amount to 49.2 per cent. Krout (2) reports that in the Sabine orchard in 1922 the substitution of Bordeaux mixture for lime-sulfur at the pink application did not reduce the percentage of scabby fruit, as compared with results following the use of lime-sulfur alone; in fact, in the case of both dry and liquid lime-sulfur, when Bordeaux mixture was substituted there was a larger percentage of scab. At the Knights and the Frost orchards, however, there was a slight decrease in the amount of scab when Bordeaux mixture was substituted for the pink application; in the case of liquid lime-sulfur this decrease was from 4 to 2 per cent in one orchard and 2 to 0 per cent in another, and in the case of dry lime-sulfur the decrease was from 8 to 3 per cent in one orchard and 2 to 1 per cent in another. We may conclude that although Bordeaux mixture under some conditions may prove slightly superior to lime-sulfur for the pink spray, there is, nevertheless, abundant evidence of the completely satisfactory control of apple scab by lime-sulfur throughout the spraying season; and it does not appear, therefore, that we have sufficient reason to devote extra labor to the preparation of Bordeaux mixture.

Atomic Sulphur.

The proprietary sulfur fungicide, Atomic Sulphur, was used in two orchards with a view to comparing it with lime-sulfur for its fungicidal efficiency and its toxicity to the sprayed tree. Enough of this material to make 100 gallons costs more than three times as much as the liquid lime-sulfur necessary to make an equal amount. Atomic Sulphur, therefore, needs to show very decided advantages over lime-sulfur if it is to compete with it in the spraying of apples.

There was this year no injury to fruit or foliage on trees sprayed with lime-sulfur or with Atomic Sulphur. It was, therefore, impossible to compare them as regards toxicity to the sprayed tree.

Mason (16) found that when apple trees were sprayed with a combination Atomic Sulphur-lime-lead arsenate spray, the foliage was uninjured, while under the same climatic conditions, foliage and fruit were burned by the lime-sulfur-lead arsenate combination.

Atomic Sulphur was used by the writer at the rate of 7 pounds to 50 gallons of water, and when it was used in combination with arsenate of lead, 4 pounds of lime slaked into a milk were added to each 50 gallons, as directed by the manufacturers. At one of the orchards, the results were as follows: Atomic Sulphur, 4.2 per cent scabby fruit; liquid lime-sulfur 2.1 per cent scabby fruit; dry lime-sulfur 4–50, 1.03 per cent scabby fruit. At this orchard, the control secured by Atomic Sulphur was somewhat surpassed by both dry lime-sulfur and liquid lime-sulfur. At the other orchard, the percentages of scabby fruit were as follows: Atomic Sulphur, 3.9 per cent; dry lime-sulfur 3–50, 4.6 per cent. At this orchard also, the results with the two materials are very nearly alike.

If Atomic Sulphur has any advantages over lime-sulfur, they are not to be found in relative efficiency in scab control, but rather in degrees of difference in toxicity to the sprayed plant. Apple orchards in which peaches are planted as fillers are sometimes sprayed with Atomic Sulphur because of the known danger to peaches in leaf from the use of commercial lime-sulfur. When this is done, we may be sure that the apples have received treatment with a fungicide which can protect them against scab infection.

Compatibility of the Ingredients in the Combination Spray as Affected by Addition of Lime, Calcium Caseinate, and Order of Mixing.

Apples are not often sprayed with lime-sulfur alone. They are now more often sprayed with a mixture of lime-sulfur, lead arsenate, nicotine sulfate, and calcium caseinate. The reaction between lead arsenate and lime-sulfur has been studied by Ruth (17) and others, and it is known that both of these materials are somewhat decomposed, one of the results being the formation of the black sludge, lead sulfide. Relative blackness of the mixture is an indicator of its lack of desirable qualities. So far as is known, the addition of nicotine sulfate does not affect this reaction. It has been shown by numerous investigators that the addition of arsenate of lead to lime-sulfur increased the fungicidal value of the latter. Although the use of such a combination spray controls apple scab as well or probably better than lime-sulfur alone, the formation of soluble arsenic as a result of the reaction increases the danger of foliage burning.

It has been found by Robinson (18) that by the addition of lime to this combination spray, the percentage of the soluble, and therefore dangerous, arsenic in the combination spray can be reduced. After standing two days, most of the lime-sulfur with lime added remained unchanged, while in lime-sulfur alone, the desirable polysulfide sulfur had all been changed into lead sulfide or thiosulfate. Bourne (19) modified Robinson's method by adding milk-of-lime to lead arsenate and then adding the two together to diluted lime-sulfur. He found this resulted in very little sediment or blackening. He diluted lime-sulfur till the spray tank was nearly full. Lime (at the rate of 10 pounds to 100 gallons of the total mixture) was slaked and water added to make a milk. Arsenate of lead was stirred into the milk-of-lime, which was then strained into the spray tank with the agitator running. Krout (2) compared liquid lime-sulfur with liquid lime-sulfur plus lime in the field. In each of the three orchards where he used it, there was no russeting of the fruit by either lime-sulfur alone, or lime-sulfur with lime added, and so the benefit of the addition of lime in reducing burning was not shown. In each of the three orchards sprayed by Krout, the addition of lime to lime-sulfur was followed by an increase in the percentage of scabby fruit over the percentage on trees sprayed with lime-sulfur without lime, the increases being 10, 3, and 8 per cent, respectively.

In the experiments of 1923, there was no russeting or burning on trees sprayed with lime-sulfur or on those sprayed with lime-sulfur plus lime. Hence in 1923, as in 1922, it was impossible to prove that the addition of lime to lime-sulfur reduced the toxicity of the fungicide to the sprayed tree. In both of the orchards where these materials were compared in 1923, a larger percentage of scabby apples was produced on trees sprayed with lime-sulfur plus lime than on trees sprayed with lime-sulfur without lime added, the increase being 1.2 per cent in one case and 5.3 per cent in the other. The indications are that the addition of lime to the lime-sulfur-lead arsenate combination spray reduces somewhat the fungicidal efficiency of the latter. In seasons when climatic conditions result in toxicity to the sprayed tree by the lime-sulfur-lead arsenate combination spray, it is possible that any small decrease in fungicidal efficiency coincident with the addition of lime would be more than offset by the decreased danger of burning described by Robinson (loc. cit.) and Bourne (loc. cit.). However, further experimental evidence is needed.

According to Regan (20) the addition of calcium caseinate spreader to lime-sulfur-lead arsenate combination spray prevents the usual decomposition and formation of black sludge. He found two pounds of calcium caseinate to be more effective in preventing this decomposition than ten pounds of hydrated lime. Lovett (21) also reports that the addition of calcium caseinate materially delays the reaction between lime-sulfur and lead arsenate in the combination spray.

Laboratory tests were made by the writer to compare the formation of black sludge in the combination spray with and without the addition of calcium caseinate. Without calcium caseinate, the color of the mixture was dark citrine[1] and with it the color was yellowish citrine, that is, considerably lighter. After standing three minutes the sludge precipitated without calcium caseinate was nearly twice

[1] Colors determined by comparison with Ridgway, Robert. Color Standards and Nomenclature. Washington, 1912.

as much as the sludge in the mixture containing calcium caseinate. Apparently the addition of calcium caseinate physically improves the mixture.

In filling the spray tank, five ingredients are or may be used, *i.e.*, water, lime-sulfur, lead arsenate, nicotine sulfate and calcium caseinate. After the water is in the tank, there are twenty-four different orders in which the other ingredients may be added. The manufacturers of calcium caseinate recommend that it be added to the water in the spray tank, with the agitator running, before the other materials are added. According to Anderson and Roth (22) the lime-sulfur is first diluted, the lead arsenate added to it with agitation, and then the nicotine sulfate added. After putting the calcium caseinate in the water in the spray tank, this is probably the order most commonly followed. Britton (23) recommends the following order for filling the spray tank: first, clean water; second, nicotine sulfate; third, calcium caseinate (if used); fourth, lead arsenate; and fifth and last, lime-sulfur. He says that when mixed in this order, especially if calcium caseinate is present, little or no discoloration or precipitation of brown sludge follows.

In laboratory tests made by the writer, the ingredients were mixed in the order named by Britton; the resulting mixture was buffy olive in color, with little precipitation. In another test they were mixed in the following order: water, calcium caseinate, lime-sulfur, lead arsenate, and nicotine sulfate. The color of this mixture was ivy green, considerably darker, with more precipitation. Several other orders of mixing were compared and the best results, based on a color test and relative sludge formation, were obtained by the following sequence after the water: first, calcium caseinate; second, nicotine sulfate; third, lead arsenate; and fourth, lime-sulfur.

Spore germination tests made with the conidia of the apple scab fungus showed that the fungicidal efficiency of the combination spray is not impaired by any order of mixing tested. But the order of mixing does affect the physical qualities of the mixture and very probably the burning of the sprayed tree. It should be added that when light colored lime-sulfur combination spray is desired, special attention should be given to washing out the spray tank. The use of calcium caseinate results in a decidedly lighter colored mixture.

Results of Dusting Treatments.

A rather extensive literature on the results of dusting for the control of apple scab has come into existence. The results do not all agree, but perhaps they are no more inconsistent than the published results of spraying experiments. In general, the control of apple scab by the use of dusts has been surpassed by that of liquid sprays. This is not surprising when we consider that spraying is a much older orchard practice than is dusting. Our knowledge of the use of liquid sprays and the schedule for their application to the apple is relatively advanced. Dusts have been used in conformity with the spray schedule, rather than according to any special dusting schedule.

It should be noted that no experiments have been conducted in Massachusetts which directly compare the results of spraying with those of dusting. Owing to the topography and plan of the several orchards, spraying and dusting experiments have been carried on in separate orchards or in separate parts of the same orchard with one check plot for the spray treatment and another for the dust treatment.

In the orchards dusted by Krout (2) in 1922 the average percentage of scabby fruit in the check plots was 75.8 and the average percentage of scabby fruit in the plots dusted with sulfur was 17.2. In the orchards sprayed by Krout, the average percentage of scabby fruit in the check plots was 79.0 and the average percentage of scabby fruit in the plots sprayed with dry lime-sulfur 4–50 was 8.0. It is evident that the dust did not give a control equal to that of the spray. The results of Massey and Fitch (8) were: in one orchard, check 93.3 per cent scab, and sulfur dust 13.5 per cent scab; in another orchard, check 43.5 per cent scab and sulfur dust 3.1 per cent scab. In an orchard dusted by Parrott, Stewart, and Glasgow (13), the results were 83.9 per cent scab in the check, and 47.8 per cent scab in the plot dusted with sulfur. Results from other years and other states could be selected either in favor of or against dusting.

In 1923, the dusting experiments here reported were conducted in three orchards. At the Stowe and the Sabine orchards, the dusting schedule consisted of five applications, *i.e.*, prepink, pink, calyx, fourth dust and fifth dust. At the Frost orchard, the trees were dusted four times, no prepink application being used.

In the Stowe orchard, where check trees yielded 37 per cent scabby fruit, trees dusted with sulfur yielded 3.7 per cent scabby fruit. At the Sabine orchard, trees dusted with sulfur bore 0.5 per cent scabby fruit, and on the check trees 48 per cent of the fruit was scabby. At the Frost orchard, where no prepink application was used, trees dusted with sulfur yielded 16.9 per cent scabby fruit, as compared with 84.5 per cent scabby fruit in the check. Sulfur dust controlled apple scab satisfactorily when applications began with the prepink, but not when the prepink application was omitted.

Calcium caseinate was thoroughly mixed with sulfur at the rate of 5 pounds of calcium caseinate to 95 pounds of sulfur. This sulfur-calcium caseinate dust was used in three orchards in plots adjoining plots dusted with sulfur only. In every case, apple scab was controlled better by sulfur alone than by sulfur with calcium caseinate added.

Plots were also dusted according to a schedule which included the use of a copper dust for the prepink and pink, or the pink applications followed by sulfur dust for later applications. At two of the orchards, there was less scab following the use of sulfur throughout the season than when copper dust was substituted for sulfur for the applications before the flower buds opened. At the other orchard, there was only a negligible difference between the amounts of scab following the two different methods of treatment. No experimental evidence was secured to indicate an advantage in using copper dust instead of sulfur dust for the early applications.

Control of Primary Infection on Leaves.

As the season advances, the work of the fungicide and the conditions under which it acts become entirely different from what they were at the first of the spraying season. There is naturally and usually an increase in the mean temperature. At the time of the early applications, all infection is from the winter spores. As soon as scab lesions appear on the young leaves, there is an increasing possibility of infection by the summer spores. In some springs, the trees are for a few days, or even a few weeks, in danger of infection from both the winter and summer spores at the same time. In the absence of sufficient moisture the ejection of the winter spores may be prolonged until after the appearance of scab on the leaves.

In 1923, ejection of winter spores from the dead leaves beneath the trees was first observed on May 2. Spore ejection continued till June 16, after which none was observed. The first scab symptoms were found on the leaves May 22. It is evident from this that the first winter spores to be ejected did not infect the trees, for the incubation period with these spores of the apple scab fungus was found by Wallace (4) to be eight to fifteen days. During the period in which winter spore ejection continued, there was rain on ten days. Whenever the leaves were wet by rain, winter spore ejection was stimulated, but it was fully as abundant on certain days when the leaves were wet with heavy dew. Winter spores were not ejected in relatively great numbers at any time the last spring. Wallace (loc. cit.) reports that in order for winter spores to infect the trees, the trees must remain wet 8 to 10 hours. Such was the condition on May 12 and 21 and on June 8, and it is probable that much of the primary infection took place on these dates.

In order to secure more information on the relative fungicidal efficiency of the several treatments, the percentages of infected leaves on trees June 18 were determined. In the Frost sprayed orchard, there were at this time 39 per cent scabby leaves on the check trees, and from 0.1 to 0.3 per cent scabby leaves on the sprayed trees, with only negligible differences between the several spray treatments. All the spray treatments were practically successful in preventing the primary infection. The results were essentially the same in both of the Knights orchards, where there were 15 and 20 per cent scabby leaves on unsprayed trees, and 0.1 to 0.2 per cent scabby leaves on sprayed plots, again with negligible differences between the different spray treatments.

Upon examining the dusted orchards, it was found that the primary infection had not been as satisfactorily prevented. In one orchard where the dust treatments began with a prepink application, the check trees had 41 per cent scabby leaves, and the dusted trees had 8 to 9 per cent scabby leaves, with only minor differences between the different dust treatments. In another orchard dusted in the same way, there were 15 per cent scabby leaves on the check trees and 3 to 4 per cent scabby leaves on the dusted trees. In the third orchard, where no prepink application was used, there were at this time 53 per cent scabby leaves on the check and 21 to 24 per cent scabby leaves on the dusted trees. This indicates the necessity of a prepink application if dust is to control the primary infection. But even where both prepink and pink applications of dust were made, relatively more primary infection occurred than in the sprayed orchards. As is explained elsewhere, the dust treatments in the orchards where dusting began with a prepink application, were entirely satisfactory in preventing the further spread of scab, that is, in preventing infection later in the season by the summer spores. It would appear that if dust is equally as efficient as liquid spraying in controlling the spread of scab during the summer, it is less efficient in preventing the primary infection in early spring. If such is the case, then for those who own both duster and sprayer, a safer procedure would be to use the sprayer for the pink application and the duster for later ones. It should not be overlooked, however, that dust satisfactorily controlled scab on the fruit when the dusting schedule included both a prepink and pink application.

Effect of Fungicides on the Tree.

The literature contains references to increased dropping of the fruit following the use of lime-sulfur. There was this year in the experimental orchards no more dropping of the fruit following any of the several treatments than that which occurred on the check trees.

There was only a negligible amount of injury to fruit or foliage on any of the sprayed or dusted plots. The trees used are McIntosh. Although burning was absent in the experimental plots, it was seen on the fruit of Baldwins following the application of sulfur dust. Childs (3) and others report that sulfur dust may cause an injury to apple fruit similar to that of lime-sulfur solution. The relation of sulfur dust burning to temperature in the case of varieties susceptible to burning needs to be further considered. As has been pointed out by Safro (24) some cases of injury attributed to lime-sulfur are primarily cases of sunburn, and the same is probably true of injury by sulfur dust. The absence of spray injury from all plots made it impossible to learn to what extent the addition of lime to lime-sulfur decreases burning, and how the latter fungicide compares with Atomic Sulphur in this respect on the apple.

Relation of Temperature of the Season to the Fungicidal Efficiency of Sulfur.

We have as yet no data on the temperature necessary for sulfur to prevent the germination of the winter spores of the apple scab fungus. Doran (25) has shown that sulfur prevents the germination of the summer spores of this fungus when the temperature is 78.8° F. for five hours. If the temperature is higher, less time is necessary and if the temperature is lower, more time is necessary. This temperature or above it was recorded in the experimental orchards on fifty days between May 7 and August 31. As the results show, the temperature conditions of the season were such as to insure the fungicidal action of sulfur, and so prevent the germination of the conidia.

If there had been fewer days during this period when the temperature reached the necessary point, it is probable that the results with Bordeaux mixture and copper dust as compared with sulfur fungicides would have appeared relatively better than proved to be the case.

Summary.

A spray schedule beginning with the pink application controlled apple scab as well as a schedule beginning with the prepink application.

Sulfur dust controlled apple scab satisfactorily when it was applied five times beginning with the prepink application, but not when it was applied four times beginning with the pink application.

Liquid lime-sulfur 1–50 and dry lime-sulfur 4–50 proved of equal fungicidal efficiency for scab control.

Less than 4 pounds of dry lime-sulfur in 50 gallons did not on the whole control scab quite as well as dry lime-sulfur 4–50.

The addition of calcium caseinate spreader to the liquid spray was followed by a very slight decrease in the percentage of scabby fruit.

The addition of calcium caseinate spreader to sulfur dust did not result in a smaller percentage of scabby fruit than when sulfur dust was used alone.

Since there was no injury to the sprayed tree by lime-sulfur-lead arsenate combination spray, it could not be proved that the addition of lime to this spray decreased its toxicity to the sprayed tree.

As good a control of apple scab was secured by the use of lime-sulfur throughout the spraying season as by substituting Bordeaux mixture for lime-sulfur for the applications before the flower buds opened.

Atomic Sulphur controlled the disease as well as did lime-sulfur. Because of the absence of burning it was impossible to determine how they compare in their effect on the sprayed tree.

Sulfur dust throughout the dusting season controlled apple scab as satisfactorily as when copper dust was substituted for sulfur dust for the applications before the flower buds opened.

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APPENDIX.

TABLE I. — *Showing Treatment of Dusted Plots with Dates of Applications, Materials used and Percentage of Scabby Fruit.*

Orchard.	Plot No.	Prepink.		Pink.		Calyx.		Fourth (or Third) Summer.		Latest Summer.		Per Cent Scabby Fruit.
		Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	
Stowe	1	Copper-lime-arsenic-dust	May 5	Copper-lime-arsenic-dust	May 10	Sulfur dust	May 21	Sulfur dust	June 11	Sulfur dust	July 18	2.9
	2	Sulfur dust	5	Sulfur dust	10	Sulfur dust	21	Sulfur dust	11	Sulfur dust	18	3.7
	3	Check (no treatment)										37.0
	4	Sulfur dust plus calcium caseinate	5	Sulfur dust plus calcium caseinate	10	Sulfur dust plus calcium caseinate	21	Sulfur dust plus calcium caseinate	11	Sulfur dust plus calcium caseinate	18	3.9
Frost	1	Check (no treatment)										84.5
	2			Sulfur dust	8	Sulfur dust	22	Sulfur dust	13	Sulfur dust	19	16.9
	3			Sulfur dust plus calcium caseinate	8	Sulfur dust plus calcium caseinate	22	Sulfur dust plus calcium caseinate	13	Sulfur dust plus calcium caseinate	19	30.7
	4			Copper-lime-arsenic dust	8	Sulfur dust	22	Sulfur dust	13	Sulfur dust	19	17.6
Sabine	1	Check (no treatment)										48.0
	2	Copper-lime-arsenic dust	4	Copper-lime-arsenic dust	9	Sulfur dust	24	Sulfur dust	12	Sulfur dust	17	4.8
	3	Sulfur dust	4	Sulfur dust	9	Sulfur dust	24	Sulfur dust	12	Sulfur dust	17	0.5
	4	Sulfur dust plus calcium caseinate	4	Sulfur dust plus calcium caseinate	9	Sulfur dust plus calcium caseinate	24	Sulfur dust plus calcium caseinate	12	Sulfur dust plus calcium caseinate	17	0.7

TABLE II. — *Showing Treatments of Sprayed Plots with Dates of Applications, Materials used and Percentage of Scabby Fruit.*

Orchard.	Plot No.	Prepink.		Pink.		Calyx.		Latest Summer.		Per Cent Scabby Fruit.
		Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	
	1		May	Dry lime-sulfur 3–50 plus calcium caseinate	May 7	Dry lime-sulfur 3–50 plus calcium caseinate	May 24	Dry lime-sulfur 3–50 plus calcium caseinate	June 13	5.08
	2			Dry lime-sulfur 3–50	7	Dry lime-sulfur 3–50	24	Dry lime-sulfur 3–50	13	7.06
	3			Dry lime-sulfur 4–50	7	Dry lime-sulfur 4–50	24	Dry lime-sulfur 4–50	13	1.03
	4			Dry lime-sulfur 2–50	7	Dry lime-sulfur 2–50	24	Dry lime-sulfur 2–50	13	5.07
	5	Dry lime-sulfur 3–50	3	Dry lime-sulfur 3–50	7	Dry lime-sulfur 3–50	24	Dry lime-sulfur 3–50	13	1.2
Frost	6	Check (no treatment)								76.0
	7	Bordeaux mixture	3	Bordeaux mixture	7	Liquid lime-sulfur	24	Liquid lime-sulfur	13	0.6
	8			Bordeaux mixture	7	Liquid lime-sulfur	24	Liquid lime-sulfur	13	1.7
	9			Liquid lime-sulfur	7	Liquid lime-sulfur	24	Liquud lime-sulfur	13	2.1
	10			Liquid lime-sulfur plus lime	7	Liquid lime-sulfur plus lime	24	Liquid lime-sulfur plus lime	13	3.3
	11			Atomic Sulphur	7	Atomic Sulphur	24	Atomic Sulphur	13	4.2

Table II.—*Showing Treatments of Sprayed Plots with Dates of Applications, Materials used and Percentage of Scabby Fruit*—Concluded.

Orchard.	Plot No.	Prepink.		Pink.		Calyx.		Latest. Summer.		Per Cent Scabby Fruit.
		Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	
Knights (A)	1	Bordeaux mixture	May 3	Bordeaux mixture	May 8	Liquid lime-sulfur	May 23	Liquid lime-sulfur	June 14	4.9
	2			Bordeaux mixture	8	Dry lime-sulfur 4–50	23	Dry lime-sulfur 4–50	14	1.06
	3			Liquid lime-sulfur plus lime	8	Liquid lime-sulfur plus lime	23	Liquid lime-sulfur plus lime	14	8.6
	4			Liquid lime-sulfur	8	Liquid lime-sulfur	23	Liquid lime-sulfur	14	3.3
	5	Check (no treatment)								45.5
	6	Dry lime-sulfur 3–50	3	Dry lime-sulfur 3–50	8	Dry lime-sulfur 3–50	23	Dry lime-sulfur 3–50	14	4.8
	7			Dry lime-sulfur 4–50	8	Dry lime-sulfur 4–50	23	Dry lime-sulfur 4–50	14	1.7
Knights (B)	1			Dry lime-sulfur 2–50	8	Dry lime-sulfur 2–50	23	Dry lime-sulfur 2–50	14	2.7
	2			Dry lime-sulfur 3–50 plus calcium caseinate	8	Dry lime-sulfur 3–50 plus calcium caseinate	23	Dry lime-sulfur 3–50 plus calcium caseinate	14	0.68
	3			Dry lime-sulfur 3–50	8	Dry lime-sulfur 3–50	23	Dry lime-sulfur 3–50	14	4.6
	4			Atomic Sulphur	8	Atomic Sulphur	23	Atomic Sulphur	14	3.9
	5	Check (no treatment)								59.3

TABLE III. — *Results of Three Years' Apple Spraying Experiments.*

Treatment.[1]	Per Cent Scabby Fruit —			
	1923.	1922.	1921.	Average.
Check	58.3	77.0	91.0	75.4
Liquid lime-sulfur	2.7	6.6	8.6	6.1
Liquid lime-sulfur plus lime	5.9	13.6	12.0	10.3
Dry lime-sulfur 4–50	1.3	8.0	6.0	5.1
Dry lime-sulfur 4–50 beginning with prepink	–[2]	0.0	–	0.0
Dry lime-sulfur 3–50	5.8	4.0	–	4.9
Dry lime-sulfur 3–50 beginning with prepink	3.0	–	–	3.0
Dry lime-sulfur 2–50	3.9	–	–	3.9
Dry lime-sulfur 3–50 plus calcium caseinate spreader	2.9	–	–	2.9
Atomic Sulphur	4.0	–	–	4.0
Bordeaux mixture at pink application followed by dry lime-sulfur 4–50	1.0	18.3	–	9.6
Bordeaux mixture at pink application followed by liquid lime-sulfur	1.7	6.0	6.0	4.5
Bordeaux mixture for prepink and pink applications followed by liquid lime-sulfur	2.7	7.0	–	4.8
Bordeaux mixture through season	–	8.6	–	8.6
Sulfur dust beginning with prepink application	2.1	17.2	–	9.6
Sulfur dust beginning with pink application	16.9	–	46.0	31.4
Sulfur dust plus calcium caseinate beginning with prepink application	2.3	–	–	2.3
Sulfur dust plus calcium caseinate beginning with pink application	30.7	–	–	30.7
Copper dust for prepink and pink applications followed by sulfur dust	3.8	–	–	3.8
Copper dust for pink application followed by sulfur dust	17.6	–	–	17.6
Copper dust through season	–	10.2	69.0	39.6

[1] Applications begin with pink unless stated as beginning with prepink.
[2] Blanks in table indicate that the treatment was not given in that year.

MASSACHUSETTS

AGRICULTURAL EXPERIMENT STATION

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THE INHERITANCE OF FERTILITY AND HATCHABILITY IN POULTRY

By F. A. HAYS and RUBY SANBORN

Determination of fact as to inheritance of characters is essential to successful poultry breeding. This work is peculiarly within the province of the Agricultural Experiment Station, for records must be made on large numbers of individual birds, the work must extend over a period of years, a wearisome amount of data must be preserved. The data recorded in this bulletin are the result of eleven years' work. Individual records were made on 886 birds. Resulting data are now analyzed statistically in the light of all that genetic science has to offer. It is through work such as this that a basis of sound fact, in poultry breeding work, will ultimately replace one based largely on opinion and tradition.

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AGRICULTURAL EXPERIMENT STATION

AMHERST, MASS.

Publication of this Document approved by the Commission on Administration and Finance

THE INHERITANCE OF FERTILITY AND HATCHABILITY IN POULTRY.

By F. A. Hays and Ruby Sanborn.

Introduction.

The importance of a thorough understanding of the mode of inheritance of factors affecting fertility of hens' eggs needs no stressing. Neither does the value of a complete understanding of the way hatching power of eggs is inherited require emphasis, for the proper functioning of the factors for high fertility and high hatchability is of fundamental and vital importance to every poultry breeder.

The purpose of this report is to consider only the question of the inheritance of fertility[1] and hatchability[2] from as many angles as our data will permit. The inheritance of these two characteristics is discussed first from the standpoint of the dams and then from the standpoint of the sires. The fact should be recognized at the outset that numerous variable environmental factors such as weather conditions, health of birds, exposure of eggs, variation within the same and different incubators, etc., are in constant operation. The combined action of these constantly varying environmental factors may largely obscure the inherent capacity of the bird to produce fertile eggs that are largely hatchable. A further lack of knowledge of the fundamental factors concerned in breeding for high fertility and high hatchability, as pointed out by Dunn ('23), makes proper matings impossible.

Data Available.[3]

The data used in this bulletin have been collected each hatching season from 1913 to 1923. All records kept represent the pullet year or cockerel year unless otherwise stated. All records were made by pedigreed Rhode Island Red birds. The attention of the reader is called to the fact that stud matings have been used almost exclusively and this will account for a lower degree of fertility than might be obtained from pen matings. Uniform methods of incubation have been used and care has been taken to maintain a definite system of management throughout the eleven-year period. Only females whose daughters were trap-nested are included in this report.

PART I.

The Female's Rôle in the Inheritance of Fertility and Hatchability.

Fortunately a measure of individual fertility and hatchability is possible in the female. The accuracy of such a measure depends very largely upon the number of eggs laid by the pullets in question during the hatching season. Some pullets will lay fifty eggs during a two months' incubation season, while others may lay as few as five or ten eggs. Fertility and hatchability records on the first type would certainly be much more significant than those on the second type. The major portion of the records here reported upon were made between the hatching dates of March 25 and May 15 of the respective years. In some cases chicks were hatched beyond the above dates, but not as a rule. Since the flock was being bred for egg production, considerable care was exercised to use pullet breeders that would lay a goodly number of eggs during the hatching season.

Section 1. Correlation between Fertility and Hatchability.

A hen to be able to produce a large number of chicks must lay highly fertile eggs. Furthermore, her eggs must hatch well. In ordinary usage, good hatching hens are those from which almost all eggs laid give rise to vigorous chicks. Fertility and hatchability are bound together in the sense that there can be no hatch-

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[1] *The term fertility as used here refers to the percentage of eggs that are fertile; the test being made on the fifth day of incubation.*

[2] *The term hatchability as used here refers to the percentage of fertile eggs hatched.*

[3] *The data used in this report were collected by Dr. H. D. Goodale until 1921; for the year 1922, by Professor William Sanctuary and the junior author.*

ability without fertility; but there may be one hundred per cent fertility and zero hatchability, or there may be only five per cent fertility and one hundred per cent hatchability.

The above facts show that the coefficient of correlation between fertility and hatchability could neither be zero nor negative. Pearl ('09) found a correlation of $-.127 \pm .071$ between the percentage of infertile eggs and the percentage of fertile eggs hatched from pullets. Such a factor, in view of the large probable error, indicates no sensible correlation between the degree of fertility and the percentage of fertile eggs hatched.

In table 1 presented below, the percentage of fertile eggs from 758 pullets is correlated with the percentage of fertile eggs hatched. These percentages represent each pullet's average fertility record and her average hatching record for the season. The records were obtained in eleven breeding seasons. The table includes all pullets used as breeders during the period covered, except those showing zero fertility. The zero-fertility class had to be omitted because zero fertility always means zero hatchability, and if the fifty-three pullets that laid no fertile eggs were included, a spurious correlation would arise and not the true correlation coefficient.

TABLE 1.—*Correlation Between Fertility and Hatchability.*

		PULLETS' HATCHABILITY, PER CENT.																				
		0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
Pullets' Fertility, Per Cent.	1–4																					
	5–9	4																			2	6
	10–14	2						1						1							1	5
	15–19	2					1					1		1							1	6
	20–24	5					1	2				1	1				1	1	1		1	14
	25–29	1		1			2					1		2			2	1			2	12
	30–34	3		1			1				1						1				3	10
	35–39	1					1			1		1	1	5	1		1				2	14
	40–44	3		1	1				1			2				4		1			1	14
	45–49	3					1			2				1		2	3			2		14
	50–54	3				1			1			1	2	2	1	1	4	1		1	5	23
	55–59	1	1			1			1	1	1			1	1	1	2			1	1	13
	60–64		1		1	2		2					1	3	2	2	6	1		2	1	24
	65–69	6	1		1	2	2	2	1	1	2	2	1	7	1	3	4	3			1	40
	70–74	5	1	1			3	1	2		1	2	3	4	3	2	3	6	2		2	41
	75–79	4	1	3	1	1		2	1	1	3	1	4	3	1	3	5	1	3	2	2	42
	80–84	1	2	2		4		2	1	2		7	2	6	6	3	4	4	4		3	53
	85–89	5	1		3	3	1	3	7	4	7	3	5	7	9	9	4	2	2	1	1	77
	90–94	10		3	1	2	3	4	4	3	2	3	3	11	8	5	8	9	8	4		91
	95–100	28	5	4	10	5	7	10	9	9	7	13	12	20	22	15	22	17	18	20	6	259
	f.	87	13	16	18	21	23	29	28	24	24	38	35	74	55	50	70	47	38	33	35	758

Constants calculated from Table 1.

Mean fertility	$.688272 \pm .005466$
Fertility standard deviation	$.2231 \pm .003865$
Mean hatchability	$.637875 \pm .007119$
Hatchability standard deviation	$.2906 \pm .005034$
Coefficient of correlation	$.0672 \pm .024390$

Table 1 gives a positive correlation coefficient of $.0672 \pm .02439$ which must be interpreted in the light of a probable error of more than one-third as signifying almost complete independence between degree of fertility and hatchability.

From the genetic standpoint, the results in table 1 are significant. The table shows that a flock of pullets may carry the factors that are conducive to high fertility and yet lack the ability to be good hatchers. Stated simply, these results mean that the degree of fertility in a hen's eggs is an entity independent from the hatchability of her eggs.

The mean fertility shown in table 1 is .6883, while the mean hatchability is .6379. Of the total eggs laid by these pullets during the hatching season, 68.83 per cent were fertile, and 63.79 per cent of these fertile eggs hatched. Two possible avenues are open for increasing the number of chicks per pullet. *First,* Increase the percentage of total eggs that are fertile. *Second,* Increase the percentage of fertile eggs that hatch. Selection for high fertility and high hatchability is possible only where hens are used as breeders. Hens have been used to only a very minor extent in this flock. Hence there has not been much progress in fertility and only moderate progress in hatchability, as will be shown in section 17 of this bulletin. The general deduction must be made, therefore, from the study of table 1, that fertility and hatchability are independent of each other. The stability of each characteristic may next be considered.

Section 2. The Constancy of Fertility in Hens.

In order to test the constancy of fertility in hens, the records of 253 female breeders that were used first as pullets and again as yearlings have been placed in table 2. In practically all cases a different male was mated to these females the second year. If there is a sensible correlation in fertility between the pullet-year record and the yearling record from the same hens, the natural assumption must be that degree of fertility is more or less constant in the female, regardless of the male to which she is mated.

TABLE 2. — *Correlation Between First and Second-Year Fertility.*

		Yearling Hens' Fertility, Per Cent.																				f.
		0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	
Pullets' Fertility, Per Cent.	0–4	3													1						5	9
	5–9									1										1		2
	10–14							1			1										1	3
	15–19		1			2																3
	20–24																1		1	2	1	5
	25–29	1													1						1	3
	30–34														1							1
	35–39				1				1				1						1		2	6
	40–44	1																			2	3
	45–49	1										1			1				1	1	2	7
	50–54	1		1															3		2	7
	55–59														1						2	3
	60–64																	2		3	1	6
	65–69	1			1		1								1	1		1	2	3	4	15
	70–74	2							1			1			1				1	3	3	12
	75–79																1	1	2	2	3	9
	80–84	2			1	2										3	1	1	2	2	6	20
	85–89	1							1	1		1	2	1		2	1	2	1	2	5	20
	90–94			1		2				1				2	1	1		3	7	5	19	42
	95–100	2		1				1			1		1		3			7	3	8	50	77
f.		15	1	3	3	6	1	2	3	3	2	3	4	3	11	7	4	17	24	32	109	253

Constants calculated from Table 2.

Pullets' mean fertility	.7589±.011288
Pullets' standard deviation	.2662±.007982
Yearling hens' mean fertility	.7825±.012111
Yearling hens' standard deviation	.2856±.008564
Coefficient of correlation	.2733±.039238

The mean fertility of the birds used in table 2 was slightly greater for the yearling than for the pullet-year. The difference, .0236±.016579, is not great enough to be significant. The range of variability measured by the standard deviation is slightly wider as yearlings than as pullets, but the closeness of agreement in the two years signifies a degree of fixedness. From the breeding standpoint, the chief deduction that may be made from a study of table 2 is that the percentage of fertility for a pullet is a good guide as to her probable fertility as a yearling.

A positive coefficient of correlation, .2733±.039238, between the first and second year fertility supports the view that fertility is a trait that is fairly constant for the individual hen. Lamson and Card ('20) have pointed out this fact in Leghorns. Pearl ('09) found a negative correlation of .1112±.092 between infertility the first year and the second year in Barred Plymouth Rocks. Our data, however, indicate that a bird with good fertility as a pullet will probably show good fertility as a yearling.

Section 3. The Constancy of Hatching Power in Hens.

The group of 253 birds studied in table 2 are correlated for hatchability in table 3 to discover if there is a relationship between the percentage of fertile eggs hatched as pullets and as yearlings. In other words, does hatchability approach any degree of constancy in the same individual in two successive years? Does a good hatching record as a pullet mean a good hatching record as a yearling?

TABLE 3. — *Correlation Between First and Second-Year Hatchability.*

	Yearling Hens' Hatchability, Per Cent.																				
Pullets' Hatchability, Per Cent.	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4	10				2		1					2	1	1	2				1		20
5–9	2				1							1				1					5
10–14	3						1				1										5
15–19	3				1		1		1			1									7
20–24	3																				3
25–29	2	2			1							1			1		1				8
30–34								1				1			1			1	1		5
35–39	3			1			2	1					1								8
40–44		2	1		1		1	1					2	2							10
45–49	1					3	1		1		2					1					9
50–54	5		2		2	1		1			2		1	2	1		1	1		1	20
55–59	1		2	1		1	3		2	3	1		2					1			17
60–64	1				1				3	3	2	1		1	2	1	2	1		2	20
65–69	2		1	1								1	3	3	2	2	1	2	1		19
70–74	2		1	1					1	1		1	2	1	1	5	1	1	3	1	22
75–79	4					1	1	1	1	1	3		3	1		3	2	2	1		24
80–84									1		2	2		2			1				8
85–89	1	1					1			1	1		3		2	4	1	2		1	18
90–94	1									1	2		1			1	3	4		1	14
95–100	2										1			4			2	1		1	11
f.	46	5	7	4	9	6	12	5	10	10	17	11	19	17	12	18	15	16	7	7	253

Constants calculated from Table 3.

Pullets' mean hatchability	$.5678 \pm .011313$
Pullets' standard deviation.	$.2668 \pm .008333$
Yearling hens' mean hatchability	$.4791 \pm .012963$
Yearling hens' standard deviation	$.3057 \pm .009166$
Coefficient of correlation	$.4346 \pm .034409$

The mean hatchability for pullets is $.5678 \pm .011313$. The mean hatchability for the same birds as yearlings is $.4791 \pm .012963$. There is a difference of $.0887 \pm .0172$ in favor of using pullet breeders. This difference is significant in the light of its probable error. Stewart and Atwood's ('09) records with White Leghorns do not agree with these results. They found both the mean fertility and mean hatchability to be higher in hens than in pullets. Their records are scarcely comparable with ours because they did not compare the same birds. Furthermore, in a yearling or two-year-old flock, most of the poor hatchers will have been discarded if they were tested as pullets. Pearl ('09) obtained a slightly higher mean fertility in the pullet year and an insignificant difference in hatchability between pullets and yearlings, using the same flock of Barred Plymouth Rocks.

The range of variability measured by the standard deviation is significantly greater in the yearling hens. This difference may possibly be ascribed to variability in physical condition in the older birds. Hatchability, however, seems to be a trait that behaves with a good deal of constancy in hens. This fact makes the individual hatching record valuable, at least in making use of a hen for several years to increase flock numbers. The ability of the hen to transmit this hatching power to her daughters will be considered in section 5.

The coefficient of correlation calculated from table 3 is $.4346 \pm .034409$. Hatchability is therefore more constant than fertility, for the coefficient for fertility in the same flock was only .2733. In breeding for high hatchability there is ample justification for discarding the poor hatchers the first year and retaining the good hatchers to perpetuate the flock.

Section 4. Correlation in Fertility between Mothers and Daughters.

In order to discover if there is any relationship between mothers and daughters in degree of fertility, the average fertility of pullet breeders has been correlated with each of their daughters that were used for breeding as pullets. In case only one daughter was used, there was but one insertion in the table. If a pullet dam had more than one daughter used as a breeder she is paired with each of these daughters and an insertion made in the table.

Table 4. — *Correlation in Fertility Between Mother and Daughter.*

Dams' Fertility, Per Cent.	Daughters' Fertility, Per Cent. 0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4																					
5–9																					
10–14																					
15–19									1									1			2
20–24																					
25–29	1																				1
30–34												1					2		1	1	5
35–39						1								1		1			1	1	5
40–44				1						1	1			1	2			2	1	4	13
45–49								1			2						2			3	8
50–54										1				1	1			2	1	2	8
55–59	1																1		3	4	9
60–64	2				1					1			1		1		2	1	1	7	17
65–69	3		2		2	1					2		1	2	1	1	2	3	3	8	31
70–74	2				1		1	1	1		1			2	1	5	2	3	4	13	37
75–79								1			1		1	4	2	2	3	2	3	5	24
80–84	5				3	1	1				2		1	1	4	2	1	2	7	17	47
85–89	5	1		1			2	2	3	1	1	2	2	1	2	4	3	7	10	17	64
90–94	12	1	1	1	1	3	1	1	3	4	5		3	7	6	4	5	10	11	45	124
95–100	23	4	2	4	6	5	5	7	6	6	8	9	15	20	21	23	31	44	45	132	416
f.	54	6	5	7	14	11	10	13	14	14	23	12	24	40	41	42	54	77	91	259	811

Constants calculated from Table 4.

Dams' mean fertility	$.8765 \pm .003503$
Dams' standard deviation	$.1479 \pm .002477$
Daughters' mean fertility	$.7378 \pm .006831$
Daughters' standard deviation	$.2884 \pm .004830$
Coefficient of correlation	$.0147 \pm .023679$

The standard deviation in dams in fertility is .1479, while the standard deviation of their daughters is twice as great or .2884. There is a positive correlation coefficient in fertility of $.0147 \pm .023679$ between the dams and the 811 daughters that were used as breeders. Since this coefficient is less than its probable error, it can have no significance. This table must therefore indicate that a pullet with low fertility is as likely to give daughters high in fertility as is a breeding pullet that shows high fertility herself. These observations are essentially in agreement with Pearl ('09), for he found a negative correlation of $.035 \pm .072$ in infertility between mother and daughter. The conclusion seems justified, therefore, that the fertility of the dam's eggs is no indication as to the probable fertility of her daughter's eggs. In section 2, the fertility record of a pullet was shown to be a guide as to her second-year fertility. Since the dam's fertility record is not a dependable index of her ability to breed true for fertility, the only satisfactory test is the progeny test, for fertility seems to depend upon many as yet unrecognized factors, or else is not an inherited characteristic.

Section 5. Correlation in Hatchability between Mothers and Daughters.

The identical group of dams and daughters used in table 4 has again been correlated in table 5, using percentage of fertile eggs hatched.

Table 5. — *Correlation in Hatchability Between Mother and Daughter.*

Dams' Hatchability, Per Cent.	Daughters' Hatchability, Per Cent. 0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4																					
5–9							1														1
10–14													1								1
15–19	1																				1
20–24	1										1										2
25–29	3											2									5
30–34	1	1		1			1			1		2	1				1				9
35–39	4					2	1						5	3	1		2	1			19
40–44	6			2	2				3	3	1	1		1			1	1		3	24
45–49	7	3	2	1	2	1		3			1	2	3		2						27
50–54	7	2	1		1	1	1		3	1	1	1	3	1	1	7	1	1	1	2	36
55–59	10	1	3	1	4	4	3	2	4	1	2	3	9	3	5	5	2	1	3	1	67
60–64	13				3	3	4	4	3	6	3	2	8	4	7	9	4	3	3	5	84
65–69	18		1	2	4	2		2	4	2	5	4	11	6	4	7	5	2	4	3	86
70–74	8	2	1	2	2	2	4	3	1	1	9	3	6	2	3	8	5	4	3	1	70
75–79	28		4	4	3		4	3	2	4	6	2	7	12	5	8	6	9	1	7	115
80–84	11			2		1	6	3	2	2	3	4	8	5	6	6	4	10	5	4	82
85–89	11	3	3	1	1	3	2	2		1	1	4	3	8	6	9	6	6	4	5	79
90–94	6	2	1	1		2	1	3	1	2	3	2	7	6	7	7	5		6	5	67
95–100	2					2		2			2	2	3	2	3	4	6	2	3	3	36
f.	137	14	16	17	22	23	28	27	23	24	38	34	75	53	50	70	48	40	33	39	811

Constants calculated from Table 5.

Dams' mean hatchability	$.7064 \pm .003891$
Dams' standard deviation	$.1643 \pm .002752$
Daughters' mean hatchability	$.5091 \pm .007340$
Daughters' standard deviation	$.3099 \pm .005190$
Coefficient of correlation	$.1960 \pm .022805$

Table 5 undoubtedly shows that hatching power is transmitted from mother to daughter, yet while the dam's mean hatchability is .7064, her daughter's mean was only .5091. The standard deviation of dams was .1643 and their daughters' standard deviation was .3099. Thus the range of variation in daughters as measured by the magnitude of their standard deviation is almost double that of their dams. Such would be the case if a dominant factor is present for high hatchability. This relative variability is in exact agreement with the same observation on fertility as pointed out in section 4.

There is a positive correlation coefficient of $.1960 \pm .022805$ between dams and daughters in hatchability. During the progress of the experiment, the pullet breeders used on successive years came from pullet mothers that showed a good hatching percentage. In other words, the pullets that were used as breeders in any one year came from pullet dams that had laid eggs of good hatching power. According to Pearson ('03) rigid selection in parents may reduce the correlation between parent and offspring for the character in question. Since we have no fertility and hatchability records for the flock as a whole, it is impossible to mathematically measure the effect of such selection on our flock.

Pearl ('09) reports a correlation coefficient of only $.031 \pm .072$ between mothers and daughters in hatchability, but only 87 individuals were studied. Dunn ('23) states that he was unable to separate high and low hatching lines by two generations of selection. He did find, however, that families tend to become different in hatching power and to retain this difference.

Table 5 clearly indicates that hatching power is transmitted from mother to daughter, even though rigid control of the many environmental factors that modify the hatching power is very difficult. These varying conditions often obscure the true hatching ability of the pullet as an individual. The use of breeding females of high hatching power is the first step toward improving the flock in this particular characteristic. We have shown in section 3 that the hatching power of a pullet is sensibly correlated with her later hatching power. Follow this by using breeding hens that transmit high hatchability to all of their daughters. The male's part in heredity of hatchability will next be considered.

PART II.

The Male's Rôle in Inheritance of Fertility and Hatchability.

Section 6. The Constancy of Fertility in Males.

In studying the question of the inheritance of fertility and hatchability, much importance should be attached to the male side of the flock, for the male is more than half the flock from a genetic standpoint because each male furnishes half the inheritance to the progeny of several hens.

The measure of the male's fertilizing ability is the mean degree of fertility from his different matings. The accuracy of such a measure will of course depend upon whether or not high fertility is governed in inheritance by dominant or recessive factors, or whether it is independent of Mendelian factors. If high fertility depends upon recessive factors, we should expect less variation in the daughters from a hen that carries these factors pure, so that she herself is genetically highly fertile, than would be the case if high fertility is dependent on dominant factors and these were not in homozygous condition. The fact that manifestation of fertility in the eggs is probably dependent on both male and female makes the classification of either males or females with regard to this characteristic a hazardous undertaking. A careful analysis of the results from mating specific males to a number of females in successive years with conditions kept uniform would help much to explain this confusing problem.

The problem of the constancy of a male's ability to transmit a certain degree of fertility to his daughters may be elucidated by correlating the fertility of his daughters sired during his first breeding year with that of his daughters sired during the second breeding year, using pullet records in all cases. In other words, if males transmit a certain degree of fertility to their daughters in successive years, a positive correlation will exist. Such a tabulation is made from data available in table 6. Unfortunately, records on only 51 pairs of daughters are obtainable for study. The number is small because few males are used as breeders after their cockerel year.

TABLE 6.— *Correlation in Fertility between Males' First and Second-Year Daughters.*

	Fertility of Males' Second Year Daughters, Per Cent.																				f.
Fertility of Males' First Year Daughters, Per Cent.	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	
0–4	2											1					1		1		5
5–9											1									1	2
10–14																					
15–19																			1		1
20–24																	1		1		2
25–29																		1			1
30–34																					
35–39																					
40–44															1					1	2
45–49																				1	1
50–54																					
55–59																				1	1
60–64			1																		1
65–69															1	1					2
70–74																	1			2	3
75–79								1		1			1							2	5
80–84											1					1				4	6
85–89																				2	2
90–94											1							1	1	1	4
95–100					1			1			1			1	1				3	5	13
f.	2	0	1	0	1	0	0	2	0	1	4	1	1	1	3	2	3	2	7	20	51

Constants calculated from Table 6.

First-year daughters' mean fertility	.6651± .031064
First-year daughters' standard deviation	.3289± .021966
Second-year daughters' mean fertility	.7700± .025001
Second-year daughters' standard deviation	.2647± .017678
Coefficient of correlation	.2151± .090076

In table 6 the mean fertility of the first-year daughters was .6651 while the mean for the second-year daughters was .77. There is a difference of .1049±.0399, which, judged by the magnitude of its probable error, is of doubtful significance. There is also no sensible difference in the standard deviation of first-and second-year daughters. A sensible degree of correlation between first-and second-year daughters is questionable because r = .2151 ± .090076. The probable error is almost half as great as the coefficient itself. The only logical interpretation that can be placed on the limited data in table 6 is that mean fertility in the daughters of the same group of males in successive years is strikingly constant, and in the second place that a positive correlation coefficient of questionable magnitude exists between first-and second-year daughters in fertility. More data of a similar nature are required to clear up this question.

Section 7. The Constancy of Hatchability in Males.

The male's ability to transmit fertility is still questionable, as has been pointed out in section 6. In the present section the subject of the constancy of hatchability in the male, as measured through his daughters, will be considered. The same difficulties are encountered in studying this question that have already been mentioned for fertility. Possibly environmental factors are of less importance in hatchability than in fertility. Pearl ('09) believes that hatching quality is more of an innate constitutional character than is fertility. If hatching quality is dependent upon Mendelian factors in inheritance, the degree of correlation between hatchability of the eggs of first-year daughters and the eggs of second-year daughters would vary with the number of factors concerned, and with the degree of homozygosity in the males for these factors. Should there be a sensible positive correlation, it would indicate that the male as well as the female transmits hatching power to the offspring.

In table 7, the group of 51 pairs of daughters studied in section 6 is tabulated for hatchability.

TABLE 7.— *Correlation in Hatchability between Males' First and Second-Year Daughters.*

Hatchability of Males' First Year Daughters, Per Cent.	Hatchability of Males' Second Year Daughters, Per Cent. 0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4	6		1	2	1			1				2	2		3			1	1		20
5–9																					
10–14		1																			1
15–19							1														1
20–24	1																				1
25–29	1														1		1				3
30–34	1						1				1		1		1						5
35–39									1												1
40–44									1		1										2
45–49	1																	1			2
50–54	1														1		1	1			4
55–59	2																		1		3
60–64												1				1					2
65–69																1	1				2
70–74																					
75–79															1					1	2
80–84																					
85–89					1										1						2
90–94																					
95–100																					
f.	13	1	1	2	2	0	2	1	2	0	2	3	3	0	8	2	3	3	2	1	51

Constants calculated from Table 7.

First-year daughters' mean hatchability	.2965± .025445
First-year daughters' standard deviation	.2694± .017992
Second-year daughters' mean hatchability	.4484± .031130
Second-year daughters' standard deviation	.3296± .022013
Coefficient of correlation	.2996± .085972

Referring to table 7, the mean hatchability of first-year daughters is .2965, while the second-year daughters of the same male have a mean of .4484. The difference is .1519±.0336, which is a significant difference. The second-year daughters appear to be superior to the first-year daughters in hatching power. To draw any conclusion, however, on such meager data would be more than hazardous. The standard deviation does not differ significantly in the two groups of daughters.

A sensible positive correlation of .2996±.085972 appears between first-year pullet daughters and second-year pullet daughters in hatchability. Table 7 thus furnishes a very small amount of evidence that hatching power is transmitted through the male, and that it is a more constant character than would be possible were it independent of heredity.

Section 8. Relation between the Fertility of the Sire's Dam and His Phenotypical Fertilizing Ability.

As there is no direct measure of a sire's phenotypical fertilizing power, it is necessary to resort to the indirect, which is the average fertility of his mates. The degree of fertility in the sire's dam may be something of a guide to his inheritance. The pertinent question at this point is: Is the degree of fertility of a cockerel's mother a guide to his ability to fertilize the eggs of his mates? If such be the case, there should be a sensible positive correlation between sire's dam's fertility and his mates' fertility. In table 8 the dams of cockerels used throughout the eleven-year period have been tabulated with the mates of these cockerels. The record of any particular dam was used against each of the mates of her son. The total number of mates was 647.

TABLE 8. — *Correlation in Fertility Between Sires' Dams and Sires' Mates.*

	Sires' Mates' Fertility, Per Cent.																				
Sires' Dams' Fertility, Per Cent.	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4																					
5–9																		1	2	1	4
10–14																					
15–19																					
20–24				1											1	1		3	3	2	11
25–29																					
30–34																					
35–39												1	1		1			1		9	13
40–44																					
45–49																					
50–54																					
55–59															1	1	1	2	1	12	18
60–64							1	2		1	1	1	2	1	3		7	5	4	15	43
65–69						1			1	2		1	1	7	4	4	4	2	7	15	49
70–74						1	1		1					2	2	2	3	4	14	21	51
75–79					1					1				2		1		2	2	6	15
80–84			2		2		3	3	2	1	5		5	5	10	6	9	11	23	48	135
85–89									1						1	1		2	3	18	26
90–94						1		2	1	1		4	2	1	3	2	5	10	15	46	93
95–100				1			1	2	3	3	1	1	6	5	4	9	14	14	26	99	189
f.			2	2	3	3	6	9	9	9	7	8	17	23	30	27	43	57	100	292	647

Constants calculated from Table 8.

Sires' dams' mean fertility	.8157±.004492
Sires' dams' standard deviation	.1694±.003176
Sires' mates' mean fertility	.8531±.004587
Sires' mates' standard deviation	.1730±.003244
Coefficient of correlation	−.1890±.025363

The mean fertility of the sires' mates is .0374±.00642 greater than the mean of the sires' dams. This is a small but significant difference and indicates that more attention was given to fertility from the female standpoint than from the male standpoint. The standard deviation is almost identical for both groups of females. A negative coefficient of correlation of .1890±.025363 appears rather difficult to explain. It certainly does indicate that the degree of fertility shown by sire's mother is not an index to the degree of fertility that such a sire will exhibit in his mates — his phenotypical fertilizing ability. This negative correlation may be due to selection of females to be used as breeders with more regard to high fertility in ancestry than is practised in selecting male breeders; or possibly males from the very fertile ancestry were mated to pullets that were lacking in fertility but otherwise desirable.

Section 9. Relation between the Hatchability of the Sire's Dam and His Phenotypical Hatching Ability.

The question of hatchability may be considered by the same methods used in section 8 in studying fertility. The identical group of birds is again tabulated for hatchability in table 9.

TABLE 9. — *Correlation in Hatchability between Sires' Dams and Sires' Mates.*

	Sires' Mates' Hatchability, Per Cent.																				
Sires' Dams' Hatchability, Per Cent.	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4													1	1					1	1	4
5–9																					
10–14																					
15–19					1							1			2	1					5
20–24																					
25–29									1		1		1	2	1	2		2			10
30–34		1			1		1		4	3	4	2	4	3	1	1		1		1	27
35–39										1	1		1				1		1		5
40–44									1	4	1	1	2	1		2	2				14
45–49				1	1	1	3	3	2	3	2	4	2	4	3	2	1	3			35
50–54						2	1		4	1	3	4	4	4	4	2	2	1	2		34
55–59						1	3	3	1	1	5	2	7	5		3	3	3	2	2	41
60–64				1		1		2	3	4	6	3	8	4	5	10	5	2	3	2	59
65–69				1		2	2	1	2	2	2	1	2	2	7	6	3			2	35
70–74	1	1	1		1	2	4	6	4	3	4	7	6	7	8	9	7	6	2	8	87
75–79				1	2	1	2	1	1	3	4	2	10	9	7	11	3	4	2	3	66
80–84		2	1		2		1	1	1	1	8	7	5	6	6	6	7	10	9	1	74
85–89				1	1	2	1	3		3	3	3	5	7	7	6	2	3	1	1	49
90–94				1			1		1				3	2	6	8	4	5	5	1	37
95–100				1		2	2		2	1	2	1	6	10	4	8	8	9	6	3	65
f.	1	4	2	7	9	14	21	20	27	30	46	38	67	67	61	77	48	49	34	25	647

Constants calculated from Table 9.

Sires' dams' mean hatchability	.6977±.005115
Sires' dams' standard deviation	.1929±.003617
Sires' mates' mean hatchability	.6488±.005229
Sires' mates' standard deviation	.1972±.003698
Coefficient of correlation	.1579±.025856

The average hatching ability of the sires' dams is .6977±.005115, while that of the sires' mates is .6488±.005229. There is a difference of .0489±.007314, which means that the males used as breeders came from dams of higher hatching power than was inherent in the pullets to which they were mated. The almost identical standard deviation for the two groups points to a similar variability in hatching power for the two.

The coefficient of correlation between the sires' mothers and their mates is .1579 ±.025856, a small but sensible correlation. Possibly this can be interpreted as meaning that males tend to show a phenotypical hatching power comparable with that of their dams. In selecting cockerels for breeders, hatching power of their dams is something of a guide to their ability to contribute hatching power to the eggs they fertilize. There is considerable probability that the male does influence the hatching power of his mates' eggs.

Section 10. Relation of Sire's Average to his Daughters' Individual Fertility.

In considering the fertilizing and hatching power of males, it is necessary to use some measure of their phenotypical character. This fact has been pointed out by Pearl ('09) and, as he states, the average fertility and hatching power of hens mated to a male may be used as his index. In table 10 the average fertility of each sire from his different mates is tabulated against the fertility of each of his daughters. This average figure for each sire is thus inserted a number of times to correspond with the number of his daughters that were used as breeders.

Table 10. — *Correlation in Fertility Between Sires' Mates and Sires' Daughters.*

Sires' Mates' Fertility, Per Cent.	Sires' Daughters' Fertility, Per Cent.																				f.
	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	
0–4																					
5–9																					
10–14																					
15–19																					
20–24																					
25–29																					
30–34																					
35–39																					
40–44																					
45–49																		1			1
50–54																					
55–59											1	1		2	1		2		2	4	13
60–64																			1		1
65–69								1							1		2	4	6	3	17
70–74								1	1		1		1	1			1	1	1	11	19
75–79					1		1	1		1			1		2	4	1	5	2	14	33
80–84				1							1	1	2	3	4	3	5	4	11	11	46
85–89						1				2	1	1			5	2	8	4	8	22	54
90–94						1		1	3	1	1		5		4	3	3	10	12	34	78
95–100				1	1	1		2	2	1	1	2	4	13	8	5	13	17	21	58	150
f.				2	2	3	1	6	6	5	6	5	13	19	25	17	35	46	64	157	412

Constants calculated from Table 10.

Sires' fertility mean	.8761±.003522
Sires' fertility standard deviation	.1060±.002491
Sires' daughters' mean fertility	.8416±.005599
Sires' daughters' standard deviation	.1685±.003959
Coefficient of correlation	.0244±.033211

A difference, amounting to .0345±.006614, will be observed between the sires' mean fertility and their daughters' mean fertility. This significant difference is easily explained if the same factors are operating to affect fertility of males and females. A wider range of variability in the daughters as compared with their sires, measured by the standard deviation, seems to indicate that there is little or no constancy in fertility between father and daughter.

No sensible correlation in fertility exists between sire and daughters as table 10 shows. In the face of this fact, there is no evidence that factors for fertility are transmitted from sire to daughter. In other words, fertility does not seem to be an inherited trait that is transmitted from parent to offspring, as has already been shown in both tables 4 and 10.

Section 11. Relation of Sire's Average to Daughters' Individual Hatchability.

The same group of birds used in table 10 is correlated in table 11 to study the relationship between sire and daughters in hatching power.

TABLE 11.—*Correlation in Hatchability between Sires' Mates and Sires' Daughters.*

Sires' Mates' Hatchability, Per Cent.	Sires' Daughters' Hatchability, Per Cent.																				f.
	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	
0–4																					
5–9																					
10–14																					
15–19																					
20–24																					
25–29									1		2										3
30–34																					
35–39																					
40–44								1		1		1				2					5
45–49			1							2	3	1				2	1	2			12
50–54								4	4	1	2	5	4	8	2	4	1	2	2	2	41
55–59							1	1	1	1		6	10	1	5	3	3	4	3	1	40
60–64				2	3	1	3	2	1	4	5	1	6	6	8	6	4	5	2	3	62
65–69				2		2	1	3	2	2	2	3	5	2	5	9	4	3	1	2	48
70–74					1	2	3	1	2	2	5	5	10	10	8	10	3	8	8	4	82
75–79						1	1	2	1	2			2	1	2	5	4	2	3		26
80–84	1						1				6	1	7	10	4	11	8	4	4	3	60
85–89														1	2	2	3	2	4	1	15
90–94										1			2		5	3	2	2	2	1	18
95–100																					
f.	1		1	4	4	6	10	14	12	16	25	23	46	39	41	57	33	34	29	17	412

Constants calculated from Table 11.

Sires' hatchability mean	$.6824 \pm .004084$
Sires' hatchability standard deviation	$.1229 \pm .002888$
Sires' daughters' mean hatchability	$.6753 \pm .006217$
Sires' daughters' standard deviation	$.1868 \pm .004396$
Coefficient of correlation	$.2268 \pm .031523$

The mean hatchability of the sires is almost identical with that of the daughters. This is in striking contrast to the mean of dams and daughters given in table 5 where the figures are $.7064 \pm .003891$ and $.5091 \pm .003740$, respectively. Such evidence might be interpreted as showing that a closer relationship exists between sires and daughters than between dams and daughters in hatching power. Such a relationship is probably due entirely to the somewhat dissimilar methods for measuring hatching power in sire and dam. The range of variability is greater in daughters than in sires evidently because of the variable nature of the males mated to these daughters.

The coefficient of correlation between sires and daughters is $.2268 \pm .031523$. Comparing this factor with the factor calculated from table 5 where mothers and daughters are concerned, the two are found to be of almost identical magnitude when their probable errors are considered. Table 11 furnishes convincing evidence of the heritability of hatching power. In this instance, hatching power of sires is carried on in their daughters. Table 11 further points to the necessity of using tested males in developing a flock carrying uniformly high hatching power.

Section 12. Relation of Sire's Dam to his Daughters' Fertility.

In section 8 the relation between sire's dam and his phenotypical fertilizing ability has been considered. A negative relationship was found to exist in that case. The present section is an attempt to discover if the sire transmits to his daughters a degree of fertility similar to that of his dam, so that when these daughters are mated with other males their probable fertility may be forecasted. In table 12, 748 pullet fertility records are tabulated with the fertility records of their sire's mother as a pullet.

TABLE 12.—*Correlation in Fertility between Sires' Dams and Sires' Daughters.*

Sires' Dams' Fertility, Per Cent.	Sires' Daughters' Fertility, Per Cent. 0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4																					
5–9															1		1	1	1		4
10–14																					
15–19																					
20–24	1										1		1	1			1	2	1	3	11
25–29																					
30–34																					
35–39													1			2			1	3	7
40–44																					
45–49																					
50–54																					
55–59	1										2				1	1	1	2	4	5	17
60–64	2	1			4	1	1	1	1		1		2	5	4	4	2	1	3	17	50
65–69	1			1	2	3		2		2	2			1	4	4	6	5	6	28	67
70–74	5				1	2		4	2	2	2	2	1	7	4	2	7	3	7	21	72
75–79		1					1				1					1	1	3	1	9	18
80–84	15	2	1	2	1			3	1	1	3	2	4	6	6	9	5	9	27	52	149
85–89	1				1				1	1		1	1	1	1	3	3	4	4	7	29
90–94	14	1	1			1	3		2	3	6	3	4	5	7	5	10	16	14	29	124
95–100	12		1	3	5	1	3	4	6	5	4	4	9	7	12	8	13	27	19	57	200
f.	52	5	3	6	14	8	8	14	13	14	22	12	23	33	40	39	50	73	88	231	748

Constants calculated from Table 12.

Sires' Dams' Mean Fertility	.8183± .003909
Sires' Dams' Standard Deviation	.1585± .002764
Sires' Daughters' Mean Fertility	.7364± .007108
Sires' Daughters' Standard Deviation	.2882± .005026
Coefficient of Correlation	− .0501± .024599

The mean fertility of the dams of the males used in this study is .0819±.008112 greater than the mean for the daughters of these males. The males used, therefore, came from dams of high fertility but the daughters of these males failed to measure up to such a standard. The standard deviation of the daughters is almost twice as great as for the sires' dams, showing that the daughters are a highly variable lot. The coefficient of correlation is negative but insignificant because of the magnitude of its probable error. The conclusion seems justified, therefore, that the degree of fertility of a sire's dam is no index to the degree of fertility that his daughters will exhibit.

Section 13. Relation of Sire's Dam to his Daughters' Hatchability.

If the hatching power of a sire's dam is something of an index to his probable inheritance of factors affecting hatchability, such relationship will appear when the hatchability records of the daughters are tabulated with the records from the sires' dams. Table 13 is thus made up of the same birds used in table 12.

TABLE 13.—*Correlation in Hatchability between Sires' Dams and Sires' Daughters.*

	Sires' Daughters' Hatchability, Per Cent.																				
Sires' Dams' Hatchability, Per Cent.	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4																					
5–9																					
10–14																					
15–19				1			1				1		2			1				1	7
20–24																					
25–29	2							1	1	1		1	1	1		1		2			11
30–34	3	3	1		2	2	2	2	1		2	1	4	1	1	3	1		1	1	31
35–39		1					1	1		1			1								5
40–44	6	1	1		2		1	1	2	2	1	2	2	3		3	2				29
45–49	16	2	4	2	2	1		1	1	2	2	4			1	1		3		1	43
50–54	2			1	2	1	3		4		2	1	3	1	1	1	2	2	2	2	30
55–59	6			1	2		1	2	1	1	3	1	1	8	2	3	2	2	3	3	42
60–64	12			1	1	3	1	1		3	3	3	10	3	6	11	6	5		3	72
65–69	1						1						1		2	1	4				10
70–74	13	2	1	1	4	3	5	6	7	2	4	8	10	12	7	11	4	12	8	2	122
75–79	12		1	3	2	3	1	3		1	4	3	6	6	7	9	8	2	4	3	78
80–84	18	2	2	2		2	5	5	3	5	3	5	14	8	9	7	7	3	6	9	115
85–89	7		1		2	1	1				3		4	4	2	1	1			2	29
90–94	2					3	1	3	2	1	1	1	2	3	2	4	4	4	1	4	38
95–100	26	1	1	4		2	4	1	1	4	3	5	5	2	5	9	3	1	7	2	86
f.	126	12	12	16	19	21	28	27	23	23	32	35	66	52	45	66	44	36	32	33	748

Constants calculated from Table 13.

Sires' Dams' Mean Hatchability	$.7019 \pm .004664$
Sires' Dams' Standard Deviation	$.1891 \pm .003298$
Sires' Daughters' Mean Hatchability	$.5096 \pm .007588$
Sires' Daughters' Standard Deviation	$.3077 \pm .005366$
Coefficient of Correlation	$.0588 \pm .024576$

The mean hatching power of the hens whose sons were used for breeding was .7019. The daughters of this group of males averaged only .5096 of fertile eggs hatched. This difference in the means amounts to $.1923 \pm .008906$ and is a much more striking difference than was observed between the same group of females in fertility. The standard deviation of the two groups agrees with that found for fertility in table 12. Again the daughters of the males show almost double the range in variability of their sires' dams.

The coefficient of correlation is here positive, but of no significance since it is a little more than twice its probable error. The lack of correlation between sire's dam and sire's daughters in hatchability can scarcely be interpreted to show that hatchability is not governed by factors transmitted from sire to daughter. The hatching power of a cockerel's dam is only the phenotypical manifestation of her ability and may be affected by her mate as well as by numerous environmental factors. She furnishes, moreover, but a part of the heritage of her son. If several factors governing hatchability are transmitted equally by males and females and if both parents have an influence on the hatching power of eggs laid and fertilized, respectively, this apparent independence of hatching power in inheritance will be explained.

If fertility be governed by genes transmitted in Mendelian fashion and without sex-linkage, this fact should be brought out by correlating the sire's record with his son's record. The only measure is the fertility record of the eggs laid by females mated to such males. If it were possible to compare males by a system of mating to the same group of females, the variable factors could be reduced to the male side alone. Such a system seems impossible to attain because of numerous factors too well understood to require mention.

Section 14. Relation of Sire and Son in Fertility.

TABLE 14.—*Correlation in Fertility between Sires and Sons.*

		Sons' Fertility, Per Cent.																				
		0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
Sires' Fertility, Per Cent.	0–4																					
	5–9																					
	10–14																					
	15–19																					
	20–24																					
	25–29																					
	30–34																					
	35–39														1		2					3
	40–44																		1			1
	45–49					1															2	3
	50–54																					
	55–59																	1			1	2
	60–64																				1	1
	65–69										1				1	1					3	6
	70–74								1								1	4	1	3	4	14
	75–79																		1	2	4	7
	80–84						1					1		1		1		3	3	3	6	19
	85–89								1							2	1	2	2	2	5	15
	90–94								1	1				1	2	2	1	2	3	3	9	25
	95–100								1	3	2		1	2	3	3	3	6	6	12	32	74
	f.					1	1		4	4	3	1	1	4	7	9	8	18	17	25	67	170

Constants calculated from Table 14.

Sires' Mean Fertility	.8682 ± .007041
Sires' Standard Deviation	.1361 ± .004979
Sons' Mean Fertility	.8441 ± .008660
Sons' Standard Deviation	.1674 ± .006124
Coefficient of Correlation	.0685 ± .051486

In table 14 each pullet mate of a sire is paired with a pullet mate of his son. The number of pairs concerned is 170 and the number of sires included is about the same as the number of sons included. The mean fertility of the sires and their sons is not significantly different, and the range in variability of sires and sons, as measured by the standard deviation, is about the same. The coefficient of correlation is very small and its probable error renders it negligible. The only conclusion that may be drawn from this small amount of data is that either the fertility record of a male's mates is not a reliable index to his inherent fertilizing ability, or else degree of fertility is not transmitted from sire to son.

In the next section the relation of hatchability of sire and son will be considered for the same birds that were used in studying fertility.

Section 15. Relation of Sire and Son in Hatchability.

TABLE 15. — *Correlation in Hatchability Between Sires and Sons.*

Sires' Hatchability, Per Cent.	Sons' Hatchability, Per Cent. 0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–100	f.
0–4																					
5–9																					
10–14																					
15–19											1										1
20–24																1					1
25–29							1		1							1	1			1	5
30–34												1	1								2
35–39					1		1	1			1		1	1			1				7
40–44					1					3	1			1	2	1		1			10
45–49							2				1	2	1	2	1	1					10
50–54								1			1	1	2	1	1			1	1		9
55–59							1	1	1		1	1	4	4	1					2	16
60–64										1	3		1	1	3	2	1		1	1	14
65–69					1								1	1	2	4	1	2	1		13
70–74									2	1	1		1	1	1	1		1		1	10
75–79				1						1		1	3	3		4	1	2	1	1	18
80–84						1		1		1	1	2	3		1		1	1		1	13
85–89									1	2	2		3	1	3	1		1			14
90–94				1				1			1			2	2	3	1	1			12
95–100				2		1		1			1		1	1	2	2	1	1	1	1	15
f.				4	3	2	5	6	5	9	15	8	22	19	19	21	8	11	5	8	170

Constants calculated from Table 15.

Sires' Mean Hatchability	.6738± .010274
Sires' Standard Deviation	.1986± .007265
Sons' Mean Hatchability	.6418± .009720
Sons' Standard Deviation	.1879± .006873
Coefficient of Correlation	.0755± .051440

Reference to table 15 shows that the mean degree of hatchability is almost the same in sires and sons. The two groups are also closely similar in standard deviation. There is no sensible correlation between father and son in hatchability. The degree of correlation here is practically the same as that observed for fertility in table 14. If we are using the correct measure for a male's hatchability, there is no evidence in these data to show that hatching power is transmitted from sire to son.

Section 16. Mendelian Interpretation of the Inheritance of Fertility and Hatchability.

Before entering upon a discussion of the possibilities of Mendelian inheritance of factors governing fertility and hatchability, it would seem desirable to present the mean records in the flock from year to year. These means are given below in table 16 along with the number of birds tested each year.

TABLE 16. — *Mean Fertility and Hatchability Records from the Massachusetts Agricultural Experiment Station Flock.*

Year.	Average Fertility.	Average Hatchability.	Number of Birds.
1913	.7562±.016855	.5910±.016578	73
1914	.8300±.015294	.5793±.016514	67
1915	.8308±.012692	.5613±.013015	118
1916	.8834±.010973	.6469±.015942	62
1917	.9158±.009776	.6217±.014709	78
1918	.8821±.009917	.6502±.013599	89
1919	.8882±.014611	.6941±.014602	56
1920	.8647±.014243	.6861±.017473	51
1921	.9107±.012241	.7483±.014129	59
1922	.8746±.010910	.7449±.011125	89
1923	.7749±.011944	.7051±.011399	144

The fertility mean has fluctuated appreciably from year to year and has not increased during the past six years. The low fertility of 1923 can be attributed to no other cause than adverse weather conditions throughout the winter and spring months. The majority of the males seem to have suffered from more or less frosting of combs and wattles during the winter of 1922–23. The basis of selecting breeding males for 1923 was not voluntarily changed from that of previous years. The general deduction must therefore be made, as Pearl ('09) has done, that fertility is dependent largely upon environmental factors and that it is not an inherent characteristic that is transmitted in inheritance.

Table 16 indicates an increase of .1141±.0206 in mean hatchability from 1913 to 1923. This increase is mathematically significant. There has been a gradual upward trend in mean hatching power since 1915. This increase has accompanied the use of breeding pullets and breeding cockerels from mothers showing good hatching power. The .04 drop in hatchability in 1923 is within the range of probability and need not be considered.

Relation of Male to the Hatching Power of his Mates' Eggs.

Unmistakable evidence is available to show that the male contributes to the hatching power of his mates' eggs. For want of any more suitable term we have used "male's phenotypical hatching power" to express the male's part. In table 9 a positive correlation coefficient of .1579±.025856 was observed between the sire's dam, and his phenotypical hatching power. A sensible correlation could not exist unless the male contributes to the hatching power of his mates' eggs.

The most conclusive evidence that the male influences the hatching power of his mates' eggs lies in the fact that the same hen shows different hatching power when mated to different males in successive years or even in the same year. Such data should be placed beside data showing the degree of constancy of hens in hatchability when mated to the same male on successive years. No data are available on the last-named question from our flock, although table 3 brings out a degree of correlation between first and second year hatchability in hens, amounting to .4346±.034409. The correlation should be much greater if the male did not play a part. In section 5 a sensible correlation between mothers and daughters was discovered. Reference to the constants calculated from table 5 shows that the hatching power of a hen is an uncertain guide to the probable hatching power of her daughters. The relative magnitude of the standard deviation of dams and daughters indicates that the phenotypical hatching power of a hen is an uncertain index of her true genetic constitution. This fact would seem to indicate that the male obscures the true genotype of the hen.

Data from the flock of the Massachusetts Agricultural Experiment Station on the constancy of hatching power in males is very limited. In table 17 a comparison is made between the first-year hatching power and second-year hatching power of

15 males. The figure used for each male represents the mean for all of his mates. These males were used on the following years: — 2 in 1913 and 1914, 4 in 1914 and 1915, 2 in 1915 and 1916, 2 in 1916 and 1917, 1 in 1917 and 1918, 2 in 1919 and 1920, 2 in 1922 and 1923.

TABLE 17. — *Mean Hatchability of Males.*

MALE NO.	First Year.	Second Year.
A323	57.00	55.80
A324	59.19	57.93
68	38.67	52.17
228	59.50	67.75
619	59.00	49.75
A271	70.71	67.40
A274	50.23	63.50
3617	53.93	64.40
5470	62.00	70.75
5581	59.29	65.00
8528	71.83	72.62
B2776	67.00	75.00
B2828	64.13	85.50
C901	76.20	65.00
C938	70.57	74.44

Mean first year, $.6128 \pm .016043$; Mean second year, $.6580 \pm .015825$; Difference in means, $.0452 \pm .0225$.

Although the data are meager in table 17, we can give it no other interpretation than as indicating that the male does partly control the hatching power of his mate through dominant factors.

The mean hatchability for the fifteen males during the first year is $.6128 \pm .016043$, for the second year $.6580 \pm .015825$. There is a difference of $.0452 \pm .0225$. This difference is just double its probable error and can therefore be of no consequence. The point we wish to emphasize in table 17 is the striking constancy in phenotypical hatching power of the same male, even when mated to different hens on two successive years. Such a degree of constancy was not found to exist in hens, as table 3 shows. The mean pullet-year hatching power of the hens was $.5678 \pm .011313$. The mean second-year hatching record of the same hens was $.4791 \pm .012963$. The standard deviation is nearly three times as great for the hens as for the males. The difference in the mean hatching power for the same hens on two successive years is $.0887 \pm .0172$, which is significant. The genetic interpretation given below will serve to elucidate several apparent complications.

Genetic Factors Concerned[1]

One dominant gene seems to be concerned in the production of high hatchability. We use the symbol H to designate this gene. There is no sex linkage and all results obtained are to be expected in a simple mono-hybrid ratio. With this hypothesis, three possible genotypes of males and females exist, namely, HH, Hh, and hh individuals. The genotype is obscured in most cases for both males and females. Such being the case, only the breeding test can be used as a guide for matings.

Hatching records on 886 females studied in this report show that these birds divide themselves into three general classes or phenotypes: — (1) Those showing hatchability of 85 per cent or above, we call high. (2) Those with a hatchability of 55 to 84 per cent, we call medium. (3) Those below 55 per cent, we call low. Since factor H has a cumulative effect, the range for the medium class is twice as great as for the high class. The minimum for the low class has not yet been determined. Below are summarized the males' phenotypical and genotypical classes:

[1] A detailed report on the genetics of hatchability will appear in another publication.

Males' Phenotypical Character.

HH males on HH hens give all high hatchability.
HH males on Hh hens give all medium hatchability.
HH males on hh hens give all medium hatchability.
Hh males on HH hens give all high hatchability.
Hh males on Hh hens give all medium hatchability.
Hh males on hh hens give all low hatchability.
hh males on HH hens give all medium hatchability.
hh males on Hh hens give all low hatchability.
hh males on hh hens give all low hatchability.

Males' Genotypical Character.

HH males on HH hens give all HH daughters.
HH males on Hh hens give 50% HH and 50% Hh daughters.
HH males on hh hens give all Hh daughters.
Hh males on HH hens give 50% HH and 50% Hh daughters.
Hh males on Hh hens give 25% HH, 50% Hh, and 25% hh daughters.
Hh males on hh hens give 50% Hh and 50% hh daughters.
hh males on HH hens give all Hh daughters.
hh males on Hh hens give 50% Hh and 50% hh daughters.
hh males on hh hens give all hh daughters.

Both parents must carry the H factor in order to be phenotypically good hatchers. Hens cannot rank in the first class unless they carry the gene H in homozygous condition and are mated to H-bearing males. These observations indicate a cumulative value for the factor H and show why the male by failure to contribute at least one-half H-bearing sperm ranks a genotypically high hen as a medium hatcher. Furthermore, both HH and Hh males probably give about the same hatching record from HH hens. The progeny test alone can give a clue to the genetic composition of males if pullets of unknown formulæ are used as breeders.

Selection for high and low hatchability did not give results in two generations according to Dunn ('23). The probable explanation is that he used in his low line genotypically high (HH) hens that gave medium hatching records because they were mated to hh males. If such were the case, no appreciable separation could take place in but two generations. There may also have been a lack of HH or Hh males in his high line. Selection for high hatchability with the female as a guide and using cockerels from hens that hatched well has been a slow but progressive process in our flock, as already shown in table 17. In table 9, the mean hatchability of the dams of the males used for breeders is about 70 per cent. This would indicate that, on the average, the breeding males came from Hh hens. Thus, only in the later years of the period could any considerable percentage of males have been of the formula Hh. A study of earlier records shows that practically all the males must have been of hh composition, because they came from medium or low-hatching dams.

SUMMARY.

1. No correlation was found between fertility and hatchability in 758 pullets.
2. Fertility in the hen behaves as an individual characteristic with a fair degree of constancy from year to year.
3. Fertility does not appear to be transmitted from mother to daughter.
4. Hatching power is more constant from year to year in the same hen than is fertility.
5. Hatching power gives evidence of being transmitted from mother to daughter.
6. Fertility in the male behaves as an individual characteristic and probably with some constancy in the same individual from year to year.
7. The fertility record of a hen is no index to the fertilizing ability of her sons.
8. Fertility does not appear to be transmitted from sire to daughter.
9. Hatchability is more constant from year to year in the same male than is fertility.
10. Fertility does not appear to be transmitted from sire to son.
11. The hatching power of a male cannot be judged by his dam's hatching record.

12. Hatching power gives evidence of being transmitted from sire to daughter.

13. Insufficient data are available on the transmission of hatching power from sire to son.

14. Fertility is evidently not an inherited characteristic.

15. Hatchability is evidently an inherited trait. High hatchability is dependent in inheritance upon one dominant gene. Both male and female parent govern the hatching record, thus obscuring the true genetic composition of either parent.

16. Genetically pure hens for high hatchability may be discovered through their own hatching record. Genetically pure males for high hatchability can be distinguished from males heterozygous for the factor only by the progeny test combined with mating tests. Both the mating and the progeny test should be used for choosing males to improve the flock in hatchability.

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MASSACHUSETTS

AGRICULTURAL EXPERIMENT STATION

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CORRELATION STUDIES ON WINTER FECUNDITY

By F. A. HAYS, RUBY SANBORN and L. L. JAMES

In plant and animal breeding it is impossible to make or effect changes in one character without running the risk of profoundly modifying, sometimes unfavorably, other characters. Such is the common experience of poultry breeders, abundantly confirmed by scientific investigation. For this reason it is essential that the relation existing between the major character in which improvement is sought, and other characters with which it may be associated, be established. In this report the results of such a study in poultry breeding are presented. The bulletin is technical in its nature, and is addressed primarily to those poultry breeders who are attempting to make thorough study of the science on which their art is based.

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AGRICULTURAL EXPERIMENTAL STATION

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CORRELATION STUDIES ON WINTER FECUNDITY

By F. A. Hays, Ruby Sanborn and L. L. James

High winter egg production is very desirable from the poultry keeper's point of view for two reasons: first, prices for eggs are much more remunerative during the winter months than at any other season; second, winter egg yield is intimately correlated with annual egg yield (Hervey 1923).

The number of eggs that a pullet will lay from first egg to March first depends upon seven pairs of Mendelian factors as has been shown by Hays (1924). This being the case, winter egg production cannot be correctly considered as a simple physiological character but rather as the manifestation of the interaction of the characters of a complex. Such traits as sexual maturity, winter pause, intensity, and broodiness have a definite and measurable relation to the number of winter eggs when large numbers are considered. Each of these four major traits affecting winter fecundity is unquestionably subjected to and modified by varying conditions that we may call "environmental" for lack of a more specific term.

In the studies reported below an attempt has been made to measure by means of the coefficient of correlation the degree of association of some measureable variables with winter egg yield. The chief value of such a study lies in the fact that, knowing the relative importance of the variables considered in relation to winter production, the breeder should be able by controlling major variables such as age at first egg, hatching date, rate of growth, etc., to attain higher winter averages and to secure greater uniformity in the winter fecundity of his flock. For example, if the flock is mated in such a way as to secure only genetically early maturing pullets, the age at first egg will range from about 150 to 210 days, while in a flock such as ours that is not genetically pure for early maturity the age at first egg ranges from 150 to 300 days.

Data Available.

A total of 959 Rhode Island Red Pullets hatched in eleven weekly broods from March 25 to June 3, 1923 are studied. This flock includes rather heterogenious breeding when winter fecundity is considered. Included in this flock are birds bred for the following characteristics: high winter and annual fecundity, non-broodiness and broodiness, good color, inbred and outbred, and hatching power of eggs. Taken as a whole, this flock may be considered good, but not equal to the standards set by those birds bred for fecundity alone. The mean of 803 birds that have complete winter records is 45 eggs.

Coefficient of Correlation

Coefficient of correlation is here used as a measure of association or dependence of one trait upon another. For example, in a particular flock of pullets if the degree of correlation between age at first egg and winter egg record is —.64, such a constant indicates that large winter records depend on early maturity in 64 birds out of every hundred, and that sexual maturity is one very important factor in determining the winter record of such pullets. A + sign before the coefficient .64 would mean that late sexual maturity is associated with large winter egg records. Other factors, such as hatching date, 150-day weight, weight at first egg, daily gain in weight, etc., may be measured in a similar manner. A comparison of the coefficients of correlation for these different factors furnishes a measure of their relative importance. Selection based on the coefficient of correlation should be applied to flocks rather than to individual birds as is evident in tables 1 and 2.

The word *mean* has the same meaning as average. *Standard deviation* shows the range of variation of a group of individuals above or below the mean or average. If the mean hatching date is 6.68 and its standard deviation is ±2.95, the interpretation is that the average range in hatching date of the flock in question is from 3.75 (6.68 − 2.95 = 3.75) to 9.63 (6.68 + 2.95). The *probable error* is written with a ± sign after each coefficient of correlation. It is used as a measure of the reliability of the figure given. Thus the degree of correlation between hatching date and weight at 150 days is −.3293 ± .0194. The meaning is that if we add .0194 to the coefficient of correlation and also subtract .0194 from the coefficient of correlation, we obtain two figures, namely, .3099 and .3487. The chances are even that the true coefficient of correlation between hatching date and 150-day weight lies inside or outside of these limits. A coefficient of correlation at least three times as large as its probable error is considered as significant.

Hatching Date

Part of the data is presented below in tabular form to show the general relation of hatching date to weight at 150 days, weight at first egg, age at first egg, and winter production, together with the average number of birds concerned in all four cases. This table will be particularly useful for general reference.

Table 1.

Hatches	Avg. No. of Birds	Wt. at 150 Days—lbs.	Wt. at First Egg—lbs.	Age at First Egg—Days	Winter Egg Prod.
March 25 (1)	41	4.22	5.73	212	58
April 1 (2)	55	4.27	5.75	211	56
April 8 (3)	61	4.23	5.94	212	57
April 15 (4)	76	4.11	5.92	221	46
April 22 (5)	69	4.18	5.94	215	48
April 29 (6)	80	3.99	5.69	217	47
May 6 (7)	105	3.89	5.62	219	39
May 13 (8)	83	4.05	5.50	208	42
May 20 (9)	113	3.72	5.22	206	41
May 27 (10)	91	3.74	5.15	202	38
June 3 (11)	82	3.72	5.13	201	34

The 150-day weight is observed to decrease rather regularly as the date of hatching advances. This fact substantiates common observation that early hatching seems to be associated with rapid growth. The weight at first egg for the different hatches shows little consistency, but as a rule, the earlier hatched birds appear to be somewhat heavier than the late hatched. The inconsistency is no doubt due in large measure to the wide range in age at first egg. Age at first egg seems to be but little dependent upon hatching date. In the last three or four hatches, however, there appears to be a reduction in the average age at first egg. Hatching date is intimately associated with winter production. In other words, the early broods as a rule lay more winter eggs than later broods. In general, hatching date appears to influence the weight at 150 days and the winter production with probably some influence upon weight at first egg and age at first egg.

As already stated, the pullets were hatched at one week intervals beginning March 25 and ending June 3. Thus eleven different age groups are represented with a range in age of 70 days. Hatching date is studied in relation to weight at 150 days, weight at first egg, age at first egg, and winter production:

Hatching Date versus Weight at 150 Days

Number of birds	959
Mean hatching date	6.68
Hatching date standard deviation	±2.95
Mean 150-day weight	3.96
150-day weight standard deviation	±.56
Coefficient of correlation	−.3293±.0194

The fact will be noted that the mean hatching date is 6.68 (May 4) instead of 6.00 (April 29) as would be the case if each hatch had produced the same number of birds. The actual date may be calculated easily in each case. It is interesting to note that the pullets averaged 3.96 pounds at 150 days old.

The coefficient of correlation between hatching date and 150-day weight is $-.3293 \pm .0194$. This is a significant correlation and substantiates common observation that early hatching tends to give larger pullets at a given age than does late hatching. In about one case out of three there was direct association between early hatching and heavy weight. In the other two cases out of three there was no relation between 150-day weight and hatching date. Other influences were operating in two cases out of three to overcome any effect of hatching date on weight at 150 days.

Hatching Date versus Weight at First Egg.

Number of birds	820
Mean hatching date	6.66
Hatching date standard deviation	± 2.92
Mean weight at first egg	5.65
Weight at first egg standard deviation	$\pm .75$
Coefficient of correlation	$-.3807 \pm .0201$

The mean weight at first egg is 5.65 pounds. The coefficient of correlation between hatching date and weight at first egg is $-.3807 \pm .0201$. The correlation shows that early hatched pullets tend to be heavier when they lay their first egg than do their later hatched sisters. This fact is in accord with the observations on weight at 150 days. In four cases out of ten the weight at first egg is directly associated with hatching date. Possibly the degree of correlation between time of hatching and weight at first egg is greater than that between time of hatching and 150-day weight because late hatching tends to reduce the mean age at first egg as will be shown below.

Hatching Date versus Age at First Egg.

Number of birds	840
Mean hatching date	6.64
Hatching date standard deviation	± 2.92
Mean age at first egg	210.99 days
Age at first egg standard deviation	± 28.91
Coefficient of correlation	$-.1487 \pm .0228$

The mean age at first egg is 210.99 days and its standard deviation is 28.91. Thus the age range is wide as will be observed from the relative magnitude of standard deviation and mean.

The coefficient of correlation is negative and amounts to $.1487 \pm .0228$. Thus in one case out of seven late hatching is associated with early sexual maturity. Such a constant suggests that late hatching tends to reduce the length of growth period prior to laying and this is in part responsible for the lighter weight at first egg in late pullets compared with early ones as was pointed out in the previous section.

Hatching Date versus Winter Production.

Number of birds	802
Mean hatching date	6.59
Hatching date standard deviation	± 2.97
Mean winter production	44.48
Winter production standard deviation	± 23.06
Coefficient of correlation	$-.2920 \pm .0218$

The mean egg production of the 802 birds studied up to March first is 44.48. The magnitude of the standard deviation shows a wide range in winter fecundity within the flock. This wide range in fecundity is to be expected because of the range in hatching date and because of the range in age at first egg as well as because of genetic differences in the individuals in winter pause, intensity, and broodiness.

A negative coefficient of correlation amounting to .2920±.0218 exists between hatching date and winter production. All other conditions being the *same*, there could not but be a negative correlation because the early hatched pullets have longer to lay. The fact that in less than one case out of three is early hatching directly associated with greater winter egg yield can be due only to the condition that a good percentage of early hatched pullets complete their winter cycle of laying and lose considerable time in winter pause while fewer later hatched pullets actually pause.

By reducing the range in age at first egg, a more accurate measure of the degree of association between early hatching and high winter egg production is obtained. The coefficient of correlation has been calculated between hatching date and winter egg record using only those birds beginning to lay at 206 days or less. The constants obtained on this group are as follows:

Number of birds	418
Mean hatching date	6.96
Hatching date standard deviation	±3.19
Mean winter production	54.93
Winter production standard deviation	±21.06
Coefficient of correlation	−.4790±.0254

In the above group of birds the 70 day range in hatching date is greater than the 50 day range in age at first egg. In other words, all birds maturing at 206 days or less are the same genetically for sexual maturity as was pointed out earlier (Hays 1924). With such a group of birds high winter fecundity is associated with early hatching in fifty per cent of the cases.

Evaluating hatching date entirely from the standpoint of desirable characteristics that are associated with winter fecundity, these deductions seem warranted from the preceding four correlation studies: 1. That early hatched pullets are heavier in weight both at 150 days old and when they lay their first egg than are late hatched ones; 2. that late hatching tends to reduce the age at first egg; and 3. that early hatching gives greater winter egg yields, but there must be a certain optimum hatching time which gives the most uninterrupted winter egg production.

Winter Production.

The total number of birds is divided into classes of winter producers with a range of ten eggs beginning with those laying from 0 to 9 eggs and ending with those laying from 130 to 139 eggs during the winter season. Winter production is studied in its general relation to hatching date, age at first egg, weight at 150 days, weight at first egg, and daily gain in weight between 150 days old and age at first egg.

Table II

Winter Egg Production	Avg. No. of Birds	Hatching Date	Age at 1st Egg	Wt. at 150 Days—lbs.	Wt. at 1st Egg—lbs.	Daily Gain Between 150 Days Old and Age at 1st Egg—lbs.
0–9 (1)	36	7.32(M.8)	266	3.65	5.95	.021
10–19 (2)	78	6.94(M.5)	244	3.87	5.97	.024
20–29 (3)	112	7.32(M.8)	219	3.92	5.68	.025
30–39 (4)	134	7.32(M.8)	212	3.89	5.52	.027
40–49 (5)	110	7.05(M.6)	205	3.92	5.37	.026
50–59 (6)	124	6.71(M.4)	203	4.05	5.47	.027
60–69 (7)	93	5.97(A.29)	196	4.16	5.46	.029
70–79 (8)	57	5.14(A.23)	193	4.17	5.46	.029
80–89 (9)	26	4.07(A.15)	189	4.27	5.51	.032
90–99 (10)	11	4.00(A.15)	177	4.67	5.61	.040
100–109 (11)	9	2.78(A.6)	179	4.37	5.30	.029
110–119 (12)	4	2.25(A.3)	182	4.19	5.25	.032
120–129 (13)	1	5.00(A.22)	165	4.57	5.75	.057
130–139 (14)	1	2.00(A.1)	165	4.27	4.75	.032

Some degree of association exists between low production and late hatching but there is lack of consistency. A striking and consistent degree of relationship is seen in table 2 between winter egg record and age at first egg. Winter egg record and 150-day weight also show considerable dependence. There is some evidence that the low producers are heavier at first egg than the high producers. The average daily gain in weight increases as we advance down the table to the heavy winter layers. The general deduction seems warranted from table 2 that low winter egg records depend in part upon late hatching, too great an age at first egg, light 150-day weight, and slow rate of gain in body weight between 150 days old and age at first egg. In order to determine specifically how important these various relations are it is necessary to resort to the coefficient of correlation.

Age at First Egg versus Winter Production.

The degree of correlation between age at first egg and annual production in Rhode Island Reds for a period of years was found to be $-.4380 \pm .0134$ (Hays and Bennett 1923). The fact that winter egg yield is definitely ended March first while annual egg record does not terminate until 364 days after a pullet lays her first egg makes the correlation more intimate between age at first egg and winter record than between age and annual production.

The correlation coefficient between age at first egg and winter production has been calculated on 803 pullets hatched in 1923 without regard to the difference in hatching date. Constants calculated from this study follow:

Number of birds	803
Mean age at first egg	210.96
Age at first egg standard deviation	± 28.62
Mean winter production	44.46
Winter production standard deviation	± 23.04
Coefficient of correlation	$-.6061 \pm .0151$

Mean age at first egg is 210.96 days. Standard deviation of age is 28.62 which exhibits the wide range in age at first egg. The mean winter production is 44.46 eggs with a standard deviation of 23.04. Again winter fecundity shows its extreme variability as would any trait dependent upon so many hereditary factors and environmental influences.

A significant negative coefficient of correlation of $.6061 \pm .0151$ appears. Thus in six cases out of ten in these pullets hatched over a period of seventy days, there is definite association between early age at first egg and high winter egg record. In other words, the length of time that a pullet has opportunity to lay previous to March first should be given very weighty consideration in breeding for winter fecundity.

To secure an exact figure on the degree of correlation between age at first egg and winter fecundity it would be necessary to make hatching date constant by studying only those pullets hatched at the same date. Such a study, we believe, would reduce the number of individuals to such an extent that the mathematical error of calculation would be inordinately large. Below are presented the constants calculated on the 154 birds in the first three hatches. The hatching date range is thus reduced to fourteen days. Constants are as follows:

Number of birds	154
Mean age at first egg	211.58
Age at first egg standard deviation	± 39.80
Mean winter production	56.90
Winter production standard deviation	± 27.61
Coefficient of correlation	$-.6413 \pm .0320$

When the range in hatching date is reduced from 70 days to 14 days the coefficient of correlation between age at first egg and winter production increases from $-.6061 \pm .0151$ to $-.6413 \pm .0320$. This fact clearly proves that hatching date is of far less importance from the winter fecundity standpoint than is age at first egg. There are two possible reasons for this: first, early sexual maturity is associated with high winter fecundity to a greater extent than merely the time element; second, late hatching has already been shown to reduce the age at first egg.

Weight at 150 *Days versus Winter Production.*

In selection of pullets to put into winter quarters or in deciding upon birds to be placed in egg laying contests, the breeder desires to know just how much stress should be laid on physical characters. Weight is one characteristic that can be definitely measured. The weight at 150 days old was secured on 800 pullets that later completed winter records. The degree of correlation has been determined between weight at 150 days and winter production. Constants calculated are as follows:

Number of birds	800
Mean weight at 150 days	3.99
Weight at 150 days standard deviation . . .	±.54
Mean winter production	44.54
Winter production standard deviation	±23.02
Coefficient of correlation	+.2758±.0220

The mean 150-day weight on the 800 pullets is 3.99 pounds with a standard deviation of .54. The mean winter production is 44.54 with a standard deviation of 23.02. Weight records show the fluctuations at the age of 150 days to be between 13 and 14 per cent.

The 800 pullets show a positive correlation coefficient amounting to .2758 ±.0220. This may be interpreted that in about one pullet out of four there is direct association between heavy weight at 150 days and a large number of winter eggs. In this particular flock, selection for heavy winter records would be about 28 per cent accurate if made on greatest 150-day weight alone.

In order to reduce the effect of hatching date on winter egg yield, studies have been made on two hatches, namely, April 15 and 22. This gives a range of but seven days in hatching date, which is practically insignificant. Constants calculated on these two hatches follow:

Number of birds	135
Mean weight at 150 days	4.16
Weight at 150 days standard deviation	±.51
Mean winter production	47.31
Winter production standard deviation	±23.93
Coefficient of correlation	+.2475±.0545

The coefficient of correlation for the two hatches does not differ significantly from that for the 800 pullets. This is evidence that hatching date had little if any effect upon the relation between 150-day weight and winter fecundity.

Weight at First Egg versus Winter Production.

The question: may the weight of a pullet in any particular variety at the time she lays her first egg be associated with high or low winter record? is of interest and importance. Should the breeder who is striving for high winter records select the heaviest pullets at first egg? These questions may be answered in general by correlating weight at first egg with winter record. Such studies have been made on 793 pullets with weight records and winter egg records. The calculated constants follow:

Number of birds	793
Mean weight at first egg	5.74
Weight at first egg standard deviation	±.73
Mean winter production	44.56
Standard deviation winter production	±23.04
Coefficient of correlation	−.1894±.0231

Mean weight at first egg is 5.74 pounds with a standard deviation of .73. The range of variability in weight is about 13 per cent and is about the same as was found at 150 days. Here is evidence that pullets weighing the most at 150 days will in general weigh the most when they lay their first egg even though there is a wide range in age at first egg.

A negative correlation coefficient of .1894±.0231 exists between weight at first egg and winter egg record. There appears to be an association between light weight at first egg and winter fecundity in about 20 per cent of the flock. The coefficient is small but significant and suggests that weight at first egg is of no very great importance in selecting for high winter record, yet there is a tendency for smaller birds to lay more winter eggs than larger birds.

By tabulating only the first eight hatches the effect of hatching date on weight is somewhat reduced. Records on 529 pullets from the first eight hatches are available for study. The constants calculated on this group are as follows:

Number of birds	529
Mean weight at first egg	5.76
Weight at first egg standard deviation	±.73
Mean winter production	47.71
Winter production standard deviation	±24.34
Coefficient of correlation	−.2963±.0269

With this group of pullets light weight at first egg is associated with high fecundity in about one case out of three. Hatching date thus appears to affect the degree of correlation.

Weight Increase versus Winter Production.

Does the rate of daily gain of pullets between the age of 150 days and the time they lay their first egg show any relationship to the number of winter eggs they will lay? Can rate of gain in the fall be considered an index to future winter production? Records are available for study on 788 pullets from which the rate of daily gain has been tabulated against number of winter eggs. The following constants appear:

Number of birds	788
Mean daily gain	.027 lb.
Daily gain standard deviation	±.00846
Mean winter production	44.59
Winter production standard deviation	±23.03
Coefficient of correlation	+.2899±.0220

This study shows the mean daily gain to be .027 pound with a standard deviation of .00846 or a range of variation in gain of about 31 per cent. The length of time over which this gain was measured varies directly with the age at first egg. Very early maturing pullets would begin laying in a comparatively few days after their 150-day weight was taken, while late maturing pullets would not begin laying until more than two months after their 150-day weight was secured. The average daily gain over a two-months' period is scarcely comparable with the average daily gain over a two-weeks' period. Yet from the standpoint of age the two are absolutely comparable in that age bears such a vital relationship to winter fecundity.

The coefficient calculated for this group is positive and amounts to .2899 ±.0220. This factor shows that in about one case out of three heavy daily gains between 150 days old and time of first egg are associated with high winter record. Heavy gainers tend to be heavy winter layers to a certain extent. In a previous section we find that the weight at 150 days is fully as reliable a guide to future winter fecundity as is rate of gain from 150 days to time of first egg.

If we eliminate the genetically late maturing birds we should expect either a higher or lower degree of correlation between weight increase and winter production than was found for the entire flock depending on whether or not the pullets gain at a different rate shortly before laying than two months or more before they lay their first egg. The records of the 413 pullets that began to lay at 206 days or less have been tabulated to show the degree of correlation between gain in weight and winter fecundity. Constants derived are as follows:

Number of birds	413
Mean daily gain	.0292
Daily gain standard deviation	±.0090
Mean winter production	54.94
Winter production standard deviation	±21.09
Coefficient of correlation	+.2055±.0318

The mean rate of gain on this group of pullets beginning to lay at from 150 to 206 days old is slightly greater than that for the entire flock. This seems to indicate that there is a tendency for the rate of gain to increase shortly before laying. But the coefficient of correlation is .2055±.0318 as compared with a coefficient of .2899±.0220 for the entire flock. Such a difference must be interpreted as evidence that the rate of gain shortly before the first egg is a less reliable indicator of future winter fecundity than is the rate of gain over a longer period before the first egg.

Weight at 150 Days versus Age at First Egg.

In order to discover if the weight of a pullet at a particular age previous to the time she lays her first egg is an index to the probable age at which she will begin laying, the 150-day weights on 846 pullets have been tabulated with their respective ages at first egg. Constants obtained are as follows:

Number of birds	846
Mean weight at 150 days	4.02
Weight at 150 days standard deviation	±.54
Mean age at first egg	210.35
Age at first egg standard deviation	±27.74
Coefficient of correlation	−.2135±.0221

A negative coefficient amounting to .2135±.0221 was obtained. Such a constant indicates that heavy weight at 150 days is associated with early production in about one case out of five. In other words, if all other conditions were kept constant, selection on the basis of heavy weight at 150 days would be advantageous for winter production.

Weight at First Egg versus Age at First Egg.

Does body weight at first egg vary directly with age at first egg or are there other influences operating so that the element of time is not alone responsible for the weight? If the element of time were alone responsible for weight variation in any particular breed, selection for early sexual maturity would reduce body weight because sexual maturity tends to check skeletal development so that later weight accumulation is largely of adipose tissue. The degree of correlation between weight at first egg and age at first egg has been calculated on 821 pullets to discover how important a relationship does exist between weight and age. The constants obtained follow:

Number of birds	821
Mean weight at first egg	5.56
Weight at first egg standard deviation	±.69
Mean age at first egg	210.66
Age at first egg standard deviation	±28.34
Coefficient of correlation	+.4604±.0185

The coefficient of correlation here shows that about half of the large pullets owe their weight to the time element. The other half are large because they possess a different capacity for growth than the first. By developing those influences, factors, or whatever they may be, to a maximum, the mean body weight should not diminish in an early maturing flock. On the face of it, the major problem here seems to be to discover just what these influences are and to make all conditions optimum for their manifestation.

Daily Gain versus Days Between 150 *Days Old and Age at First Egg*

The degree of importance of the time element in relation to daily gains may be ascertained from the degree of correlation between daily gain and number of days between 150-day age and age at first egg. Records on 814 pullets have been tabulated for study. The constants derived follow:

Number of birds	814
Mean daily gain	.0269
Daily gain standard deviation	±.0084
Mean days between weights	60.78
Days between weights standard deviation	±28.12
Coefficient of correlation	−.4145±.0196

A negative coefficient of .4145±.0196 substantiates the opinion that pullets tend to accumulate weight very rapidly just before they begin laying. We have already shown that relative rate of gain is not of much importance in selection for winter fecundity, and that the 150-day weight is just as accurate a basis of selection as rate of gain and entails only half the labor.

Winter Production versus Annual Production.

It is important to know the degree of correlation between winter production and annual production since winter egg record may conveniently be used as a basis for selecting pullet breeders. Furthermore, winter record could be used as a basis of culling for high annual records and as a basis for determining the intensity of pullets. Annual records are not yet complete on the flock being studied, consequently the winter record of three previous flocks has been tabulated against their 365-day record. A total of 845 individuals hatched in 1920, 1921, and 1922 have been studied. Constants have been calculated as follows:

Number of birds	845
Mean winter production	70.26
Winter production standard deviation	±25.07
Mean annual production	193.95
Annual production standard deviation	±40.25
Coefficient of correlation	+.6214±.0142

The above coefficient shows that in approximately six cases out of ten high winter record is directly associated with high annual record. In other words, selection for annual egg yield would be about sixty per cent accurate if made on winter trap-nest records alone. This fact makes very evident that winter egg record is of very great importance in its relation to annual record and that it is of great value in selecting pullet breeders.

In previous sections the relative importance of different measurable characteristics in relation to winter production has been discussed and the degree of correlation calculated in each case. These findings help to make clear why winter egg record as determined on a calendar basis is subject to wide variation aside from the variation caused by hereditary factors known to affect it. Such facts being known, the difficulty and uncertainty of properly classifying the pullets in distinct genotypes becomes very apparent. Such variables as have been considered must be reduced to a minimum in order to make proper matings for purposes of reducing genetic variability to a minimum. When the genetic nature of each breeding bird is discovered, definite types of matings may be made and progress assured. There can be no short road in the establishment of a flock breeding *true* for high winter fecundity.

SUMMARY

Based upon the foregoing data, the following figures show the degree of correlation between the characters stated:

1.	Between hatching date and weight at 150 days (for the entire flock)	$-.3293 \pm .0194$
2.	Between hatching date and weight at first egg	$-.3807 \pm .0201$
3.	Between hatching date and age at first egg	$-.1487 \pm .0228$
4.	Between hatching date and winter production (for the entire flock)	$-.2920 \pm .0218$
5.	Between hatching date and winter production (for the genetically early maturing birds alone)	$-.4790 \pm .0254$
6.	Between age at first egg and winter production (for the entire flock)	$-.6061 \pm .0151$
7.	Between age at first egg and winter production (first three hatches only)	$-.6413 \pm .0320$
8.	Between weight at 150 days and winter production (for the entire flock)	$+.2758 \pm .0220$
9.	Between weight at 150 days and winter production (for the hatches of April 15 and 22 only)	$+.2475 \pm .0545$
10.	Between weight at first egg and winter production (for the entire flock)	$-.1894 \pm .0231$
11.	Between weight at first egg and winter production (for the first eight hatches only)	$-.2963 \pm .0269$
12.	Between average daily gain, 150 days old to age at first egg, and winter production (for the entire flock)	$+.2899 \pm .0220$
13.	Between average daily gain, 150 days old to age at first egg, and winter production (for the genetically early maturing group alone)	$+.2055 \pm .0318$
14.	Between weight at 150 days and age at first egg	$-.2135 \pm .0221$
15.	Between weight at first egg and age at first egg	$+.4604 \pm .0185$
16.	Between average daily gain and number of days, from 150 days old to age at first egg	$-.4145 \pm .0196$
17.	Between winter and annual production, for three previous flocks	$-.6214 \pm .0142$

The most important single characteristic upon which to select pullets for winter production is age at first egg. Weight at 150 days and hatching date are of equal importance in such a selection, but of much less significance than age at first egg.

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